RESEARCH IN ADVANCED NUCLEAR DEVELOPMENT AND PLANNING

By

Michael Kuca

RECOMMENDED: ____________________________________

David L. Barnes, Ph.D., P.E.

William E. Schnabel, Ph.D., P.E.

Robert A. Perkins, Ph.D., P.E., Committee Chair

Robert A. Perkins, Ph.D., P.E., CEE Department Chair

RESEARCH IN ADVANCED NUCLEAR DEVELOPMENT AND PLANNING

A

PROJECT

Presented to the Faculty

of the University of Alaska Fairbanks

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

By

Michael Kuca, B.S.

Fairbanks, Alaska

December 2014

Executive Summary

This project began as an examination of small and mini nuclear power plants as an emergent energy technology capable of sustained base-load power generation in northern climates. Literature review immediately demonstrated Alaska should remain current on small and mini nuclear power plants because commercial vendors are promoting their products to state leaders as certain solutions. Is Alaska prepared to receive, operate, and decommission advanced nuclear technology as an alternative to traditional hydrocarbon power plants?

The graduate committee encouraged me to facilitate discussions with Alaska Center for Energy and Power (ACEP) leadership in reference to their 2010 study on small modular reactors. Gwen Holdman, Brent Sheets, and George Roe offered great encouragement for this project and allowed me to participated in nuclear related meetings with affiliates. In fall 2013, ACEP was hosting Idaho National Laboratory guests to discuss areas of common research interest. I was invited to prepare a short presentation of this project to Dr. Steven Aumeier, Director of Center for Advanced Energy Studies and Michael Hagood, Director of Program Development.

ACEP and INL later determined a mobile mini reactor design for remote terrestrial deployment represents common research interests, and INL funded three UAF student fellowships at the Center for Space Nuclear Research (CSNR) Dr. Stephen Howe, Director of CSNR, allocated a team of six graduate fellows to explore terrestrial applications of a tungsten fuel matrix currently under design for nuclear thermal propulsion. UAF students selected for CSNR fellowship included Haley McIntyre, Alana Vilagi, and me. The team designed a Passively Operating Lead Arctic Reactor (POLAR), presented the POLAR design to INL staff and industry leaders and a subsequent poster was provided for the INE conference for Alaska Energy Leaders in October 2014. In addition to exceptional engineering experience, I was able to advance the graduate project in areas of technology, policy, economics, and energy infrastructure requirements needed to accept advanced nuclear technology.

Concurrently, under a memorandum of agreement between the University of Alaska and Alaska Command ALCOM, I was able to advance the project to consider military applications of small modular reactors with ALCOM Energy Steering Group. It was in this context where I evaluated military installation energy usage in interior Alaska as compared to production of integral pressurized water reactors likely to emerge first in the commercial sector, and the ability of Alaska military to adopt this

technology. As a side project, select courses of action were prepared and briefed to the commanding general of ALCOM should the nuclear option become attractive to the military.

What began as an independent examination of small and mini nuclear power plants to satisfy a three-credit project requirement became an incredible collaboration among civilian, state, university, military, and industrial shareholders of the Alaska energy sector. Specific recognition for this report belongs to Haley McIntyre for her contribution to policy frameworks and as editor for this report, and Alana Vilagi for her contribution to process heat applications. The graduate committee along with ACEP leadership, INL-CSNR, and ALCOM should all be recognized as facilitators in this review of nuclear power in Alaska.

The following report is presented in six chapters. The first two chapters attempt to introduce the reader to the current state of commercial nuclear energy in the nation as a pretext to developing the advanced reactor designs. Modifications to the existing framework are provided and the total cost of nuclear in Alaska is considered as opportunities and barriers to deployment are evaluated. As a conclusion, scenarios are developed to explain how this technology may contribute to our energy sector in the future. This project was unfunded, and its findings are intended to present a neutral examination of emergent nuclear design in the Alaska energy sector.

Table of Contents

Page

Page

List of Figures

Chapter 1 Nuclear and Alaska's Energy Sector

Small nuclear power plants are the latest evolution in commercial nuclear power. Beginning with President Truman's Atoms for Peace speech in December 1953, the United States has advanced the use of nuclear technology for domestic heat and electricity production. As of 2013, 19.4% of the U.S. total electricity supply is produced at 100 different reactors in 31 states (NEI, 2014). Now, with the emergence of advanced nuclear reactor designs, nuclear power may become a viable option for electric and process heat applications on smaller scales, or even exist in co-generation grids with other alternative energies (Forsberg, 2013) (Power, 2010). These designs claim passive safety features and proliferation resistance with lower upfront capital commitments than the current fleet of reactors (Vuji, et al., 2012). However, at this time, these are still a developing technology and no small or mini reactor designs are currently approved for commercial operation in the United States.

Advanced nuclear power plants currently in research and development are being promoted towards remote energy markets. State leaders, to include legislators, military commanders, industry owners and citizens, are asking if this technology is appropriate to consider for the Alaskan energy sector. In reply, an evaluation of small and mini reactors is presented herein, with the assumption that initial market breakthrough will be achieved between 2022 and 2025. The goal of this report is to provide an update on new generation nuclear power plant technology, and to elucidate the opportunities and barriers for its deployment in Alaska. Further, early site permitting and stakeholder cooperatives are offered as initial courses of actions to prepare state infrastructure should this technology be selected. This paper begins with an explanation of technology used by the existing commercial fleet, along with the institutional framework in which it operates; and then proceeds to look at emergent designs and the way that present structures and systems may help or hinder their development

1.1 Why consider nuclear in Alaska?

Alaska's energy sector is unique because it consists of approximately 120 micro-grids; most inaccessible by road and solely reliant upon diesel. The dependence upon imported fuel for electric and thermal generation is costly and subject to supply chain interruptions. Shipping, storage and tertiary distribution add to the fluctuating costs of fuel; ultimately passed to the customer. Micro-grid customer costs are often so great as to be subsidized by the state in a program called Power Cost Equalization. During the period from 2000 to 2010, over $230 million was disbursed by the state to equalize the cost of remote energy; over $550 million since 1981 (Fay et al. 2012). Figure 1 demonstrates the PCE total disbursing trend over a thirty year period.

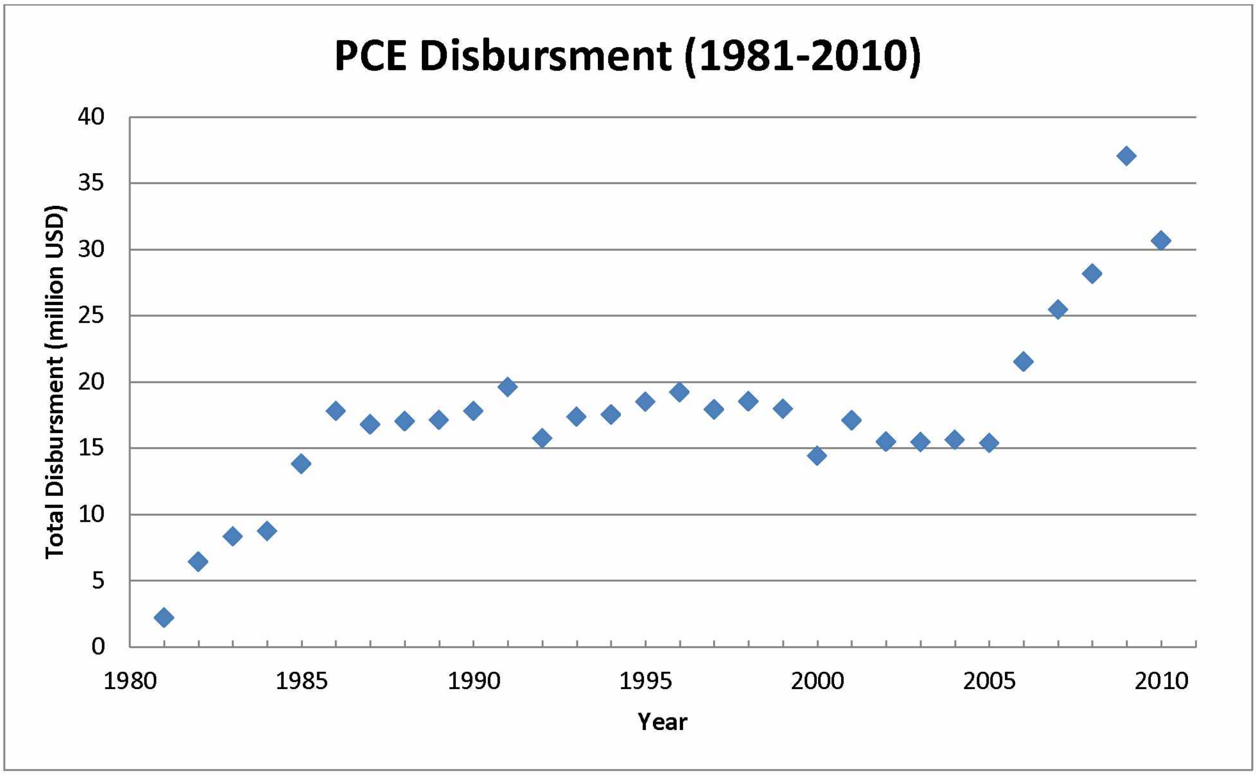


Figure 1: PCE disbursements per annum

In addition to cost fluctuations, the supply chain is unique. Fuel deliveries are primarily by barge along the west coast and distributed to communities along major river channels. This mode of transportation is only available three to six months a year due to seasonal sea and river ice. In November 2010, the Alaska supply chain infrastructure was interrupted when a large low pressure system progressed west to east across the Bearing Sea, resulting in very high seas immediately followed by early season sea ice. The US has limited icebreaking capacity in the North Pacific; therefore, Russia was called upon for assistance. Figure 2 depicts fuel barge supply lines in Alaska and the Russian icebreaker *Redna* off the coast of Nome, clearing the way for a 1.5 million gallon fuel delivery.

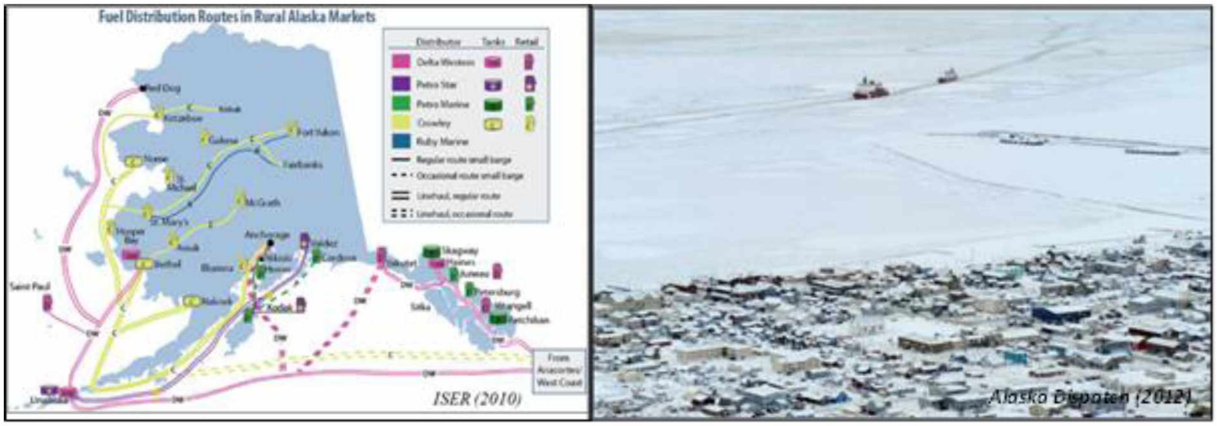


Figure 2: An illustration of barge supply chain (left) and (right) *Redna* approaching Nome, January 2012

This is merely one example illustrating a complex cost-supply matrix and highlights a regional dependence upon imported fuel. As a result, alternatives to diesel power plants are often explored in Alaska.

Utilization of nuclear power as an alternative energy source in Alaska is not a new discussion. In fact, the Army Nuclear Power Program operated a 2 megawatt-electric (MWe) reactor at Ft. Greeley in the 1960s. There is debate upon the success of this reactor which is discussed later as a function of the public sector, illustrating the need for early public involvement in the advanced nuclear power discussion. The Air Force operated 10 radioisotope thermoelectric generators (RTGs) at Burnt Mountain from early 1970s to approximately 2001. The RTG contains a radioactive material, and as this material decays, heat is released and thermocouples convert the heat to low levels of electricity. This is not a fission reaction and heat is produced at a steady, unchanged rate based on the quantity and property of isotope used. At Burnt Mountain, the RTGs provided electricity for a seismic observatory to assist in nuclear treaty verification (U.S. Congress, Office of Technology Assessment, 1994). In summer of 1992, a tundra fire at Burnt Mountain damaged some data cables but no reported damage to equipment on-site. Reportedly, state officials were unaware that the Air Force had utilized RTGs for twenty years to power the site. Consequently, Senators Stevens and Murkowski requested the Air Force consider alternative power sources at Burnt Mountain. Diesel generators now operate the seismic monitoring station.

Galena considered Toshiba's 4S reactor in 2003. It was reported that Toshiba was willing to donate the 10MWe power plant to Galena, but the regulatory process would likely take up to ten years at over $600 million (Alaska Center for Energy and Power, 2011). The project did not advance past the initial design phase, but it initiated a greater conversation in Alaska about opportunities and barriers associated with advanced nuclear energy. Also, the Galena proposal brought Alaska to the attention of the nuclear industry as a potential remote energy sector customer. In 2009, Hyperion Power Generation entered the Alaskan conversation when a Fairbanks developer proposed a self-contained modular power plant for Ester, AK. The 25 MWe reactor was estimated to cost $30 million. Ultimately, the developer in Fairbanks indicated that timeframe to implement technology was too great for further pursuit (Rettig, 2011). Hyperion became Gen4 Energy and the reactor, Gen 4 Module (G4M), along with 4S, will be evaluated in the technology section.

In 2010, the Alaska Legislature passed the Alaska Sustainable Energy Act that was meant to modernize Alaska statutes by: clarifying jurisdictional responsibility, placing nuclear on a level playing field with other alternative energies, and removing gubernatorial approval of facility siting permits. Moreover, in 2011 the state also tasked the Alaska Center for Energy and Power (ACEP), in cooperation with the Institute of Social and Economic Research, to explore the viability of new generation nuclear power plants. Together they published *Small Scale Modular Nuclear Power: an option for Alaska* which offered the state five potential actions (ACEP, 2011).

1) Continue to explore options for smaller scale (<10MWe) reactor technology.
2) Continue studies of SMR economics and technology development.
3) Identify a state technology lead.
4) Consider nuclear as one of several alternative scenarios.
5) Begin a site feasibility study for two locations in Alaska.

This report serves as an update on action items one and two with technological evaluations on new generation nuclear power plants. Action item five is addressed by recommending the early site permitting accompanied with a stakeholder cooperative capable of navigating due process.

Chapter 2 Commercial Nuclear Power and Existing Framework

2.1 Fission

A discussion in nuclear energy may be initiated with a fundamental comparison of nuclear fission to chemical combustion. Fay and Golomb provide a more detailed illustration of this comparison in their book *Energy and the Environment*. Hydrocarbon (coal, oil, natural gas) combustion occurs when a chemical (compound) is associated with the proper fuel-air ratio and temperature. Combustion releases chemical energy from the lysed hydrocarbon bond. The chemical energy release is thermal, which may provide mechanical energy for steam or gas turbines to generate electrical energy; electricity. The combustion of a hydrocarbon is a chemical reaction.

$$\text{Coal: } CH + 1.25O_2 + 4.64N_2 \rightarrow CO_2 + 0.5H_2O + 4.64N_2{}^*$$

In comparison, nuclear energy is related to the binding force holding nucleons of the atomic nucleus together; an atomic bond. For example, in nuclear fission, an isotope of uranium (^{235}U) when bombarded with a neutron usually splits into two lighter elements releasing additional neutrons (n). The additional neutrons may propagate additional fissions of heavy elements in an exponential fashion; chain reaction.

$$^{235}U + {}^{1}n \rightarrow {}^{144}Ba + {}^{89}Kr + 3{}^{1}n + 177\text{ MeV} \qquad \text{*(Fay and Golomb, 2012)}$$

The mass of the reactants is greater than the mass of the products. The mass deficit is related to energy by $E = mc^2$. Similar to combustion, energy released during fission is thermal, which may provide mechanical energy for steam or gas turbines to generate electrical energy; electricity. Energy potential in a chemical reaction may release tens of electron volts (eV) while fission may release hundreds of mega-electron volts (MeV). The difference between eV and MeV equals 10^6, or a million times greater energy available from nuclear fission as compared to chemical combustion.

2.2 Nuclear Reactor Vessel

A reactor vessel contains the nuclear core where the chain reaction occurs. The thermal energy of a reactor core is distributed to a fluid coolant which facilitates energy transfer to a conventional thermodynamic cycle. Coolant examples include boiling water, pressurized water, molten metal, or gas. Reactor vessels also contain fuel rods, moderator and control rods. The fuel rods contain fissile isotopes. Typical commercial reactors enrich uranium at 3-4%. Moderators slow neutrons that develop during fission, thus increasing probability for a neutron to be absorbed by another fissile nucleus. The moderator allows a chain reaction to propagate. Light water is a common moderator in commercial reactors which circulates around the fuel rod, while also serving as coolant fluid. Control rods are able to absorb neutrons that develop during fission, thus able to control the rate of chain reaction. The position of the control rod is related to the power output of the reactor. GE Hitachi provides a general schematic of a light water pressurized vessel as shown in figure 3.

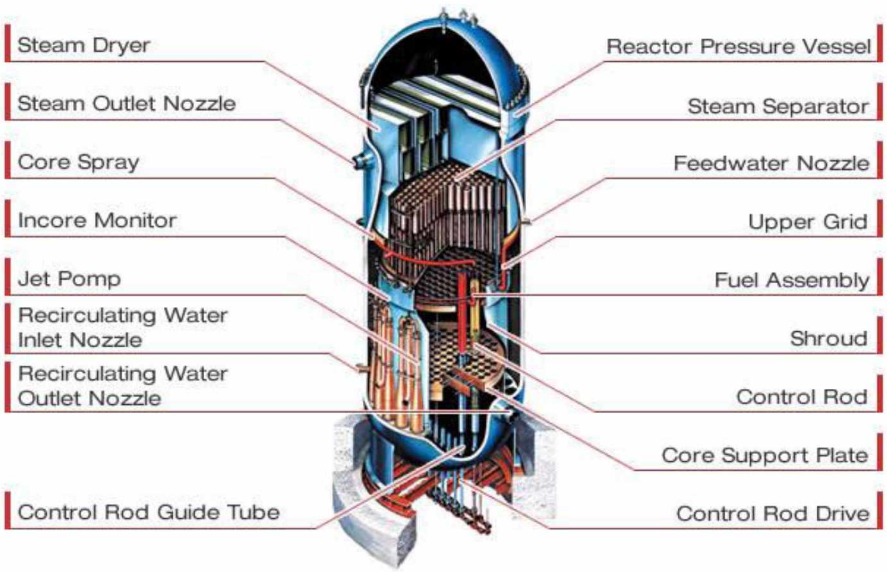


Figure 3: Schematic of light water pressurized vessel (Hitachi-GE Nuclear Energy, 2014)

2.3 Generation I – III Nuclear Power Plants

The first generation (Gen I) of commercial Nuclear Power Plants (NPPs) was available for market in the early 1960s. Westinghouse designed the first fully commercial pressurized light water reactor (LWR) while Argonne National Laboratory and General Electric developed a boiling water reactor (BWR) (Holl et al. 1985). Both reactors were rated at 250 megawatt-electric (MWe) and by the 1970s power ratings increased to 1000 MWe and above. The development and implementation of these larger, second generation (Gen II), reactors occurred during the 1970s and early 1980s. Demand for new construction slowed mid-decade, typically attributed to attitudinal factors based on Three Mile Island and Chernobyl; 1979 and 1986.

There are 100 NPPs operating in 31 states of the US. These plants achieve an average capacity factor of 90%, generate approximately 807 billion KWe per year, and account for 20% of total electric generated in the country (Heffron, 2013). The global pressurized LWR fleet has 356 nuclear power units in operation which equates to 88% of total installed nuclear power capacity (Liu & Fan, 2014).

The third generation (Gen III) NPP promotes an advanced light water reactor design (ALWR). The "advancement" refers to evolution of passive safety features, where decay heat may continue to be removed from the reactor core without external power. Westinghouse anticipates commissioning four ALWR designs by the end of the decade. A combined construction and operating license was issued in 2012 for the project (4 x 1000 MWe) with a target completion date of 2017 (Faibish, 2014). South

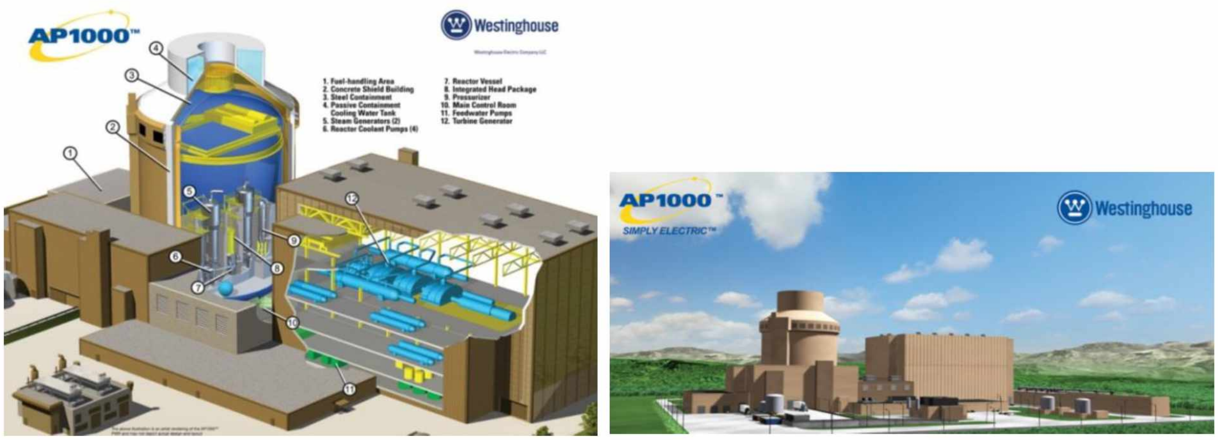


Figure 4: AP1000 ALWR (Westinghouse, 2014)

Carolina Electric & Gas plans to expand the V.C. Summer site with two Westinghouse AP1000 reactors. Southern Company plans for two additional AP1000s at the Vogtle site near Augusta, Georgia. These are the first new reactors to be approved by the NRC since the 1970s, and represents Gen III reactor emergence in the commercial sector. The announcement of Gen III reactor construction brings us to the current state of the large US commercial nuclear power fleet.

2.4 Regulatory and Existing Structure

As technology of the commercial fleet has evolved, so has its regulatory counterpart. Accounting for half of the potential cost of a project, and requiring years to successfully navigate, the nuclear regulatory process may be the single greatest hurdle to the development in the nuclear industry. This section will present the existing structure in which the commercial nuclear fleet operates as a foundation for evaluating a new generation of nuclear power plants.

The Nuclear Regulatory Commission (NRC) issues the licenses for the safety and monitoring of nuclear power plants in the United States. Prior to the creation of the NRC, nuclear regulation was the responsibility of the Atomic Energy Commission (AEC). Under the 1954 Atomic Energy Act, the AEC was given the dual objectives of promoting the use of nuclear power for commercial purposes and safeguarding the health and safety of the American public from potential nuclear hazards. Congress became concerned that these two missions may have conflicting interests and thus passed the Energy Reorganization Act of 1974, which tasked the research and advancement activities to the Energy Research and Development Agency (now the Department of Energy) and oversight to the newly formed NRC (NRC, April 2014).

2.4.1 NRC

The NRC inherited the AEC licensing structure codified in 10 CFR 50 for domestic production and utilization facilities. According to the 1954 Atomic Energy Act, those seeking to develop nuclear power for commercial use must separately pursue a construction and operation license. In the first step, the construction license, the applicant must submit financial qualification documents to cover construction and fuel costs, a Preliminary Safety Analysis Report, and a Quality Assurance Program (NRC, July 2014a). With this information, the NRC undertakes the Environmental Impact Statement (EIS) required by the National Environmental Policy Act. Once the Final EIS is complete, the applicant receives a Limited Work Authorization that allows construction of the facility to begin.

During construction, the applicant finalizes reactor design decisions and applies for the operating license. The components of this application build upon those contained in construction, with more specific data in the Final Safety Analysis Report including; mechanistic source terms, proof of design in depth, physical security and emergency preparedness plans. The advantage of this original licensing structure is that it allows for design decisions to be adjusted as construction is underway, making it possible to begin the lengthy construction process as other details are refined. However, this system presents a high level of risk to those investing in nuclear plants as it is possible to spend the money to complete the construction of a facility, only to have it not be approved for an operating license or get held up in legal hearings (Kinsey, June 12, 2014).

In 1989, the NRC sought to address this regulatory inefficiency and provide greater predictability by establishing 10 CFR 52, an alternative licensing structure that grants a Combined Operating License (COL) covering both the construction and operation of a nuclear facility (NRC, September 2009).

Furthermore, the statute creates another innovative licensing pathway, which carries some of the advantages of the previous system without the associated risks; the Early Site Permit (ESP) and Design Certification (DC). The ESP resolves site safety, environmental protection, and emergency preparedness issues independent of a specific nuclear plant design (NRC, September, 2009). An ESP can be valid for 10 – 20 years, granting a community interested in nuclear power the ability to resolve siting issues with ample time to find a reactor design suitable to their location. Similarly, the DC makes it possible for reactor designers to receive regulatory safety approval, lasting 15 years, independent of a final site. The application for a COL may be submitted without an ESP or DC, or in tandem with one or both. The benefit of having the DC or ESP prior to applying for a COL is that issues resolved during the DC or ESP may not be brought back up for hearing in the COL. However, this new system does require longer timelines up front, and prevents alterations to the reactor design without having to re-certify the Safety Analysis Report (Kinsey, June 12, 2014).

2.4.2 DOE

Functions of the AEC not assumed by NRC were managed by the Energy Research and Development Administration. Their primary tasks were energy research and development, nuclear weapons and naval reactors programs. In 1977, the agency was reorganized and merged with the Federal Energy Administration to become the Department of Energy (DOE). DOE currently manages domestic energy production and related research, nuclear weapons, navy reactors and used nuclear fuel. This section evaluates the DOE's role in advancing research and development in small and mini reactors.

The Energy Policy Act of 2005 provided substantial investment stimulus for new nuclear plant construction, investment protection for first plants, and authorized a robust research and development program. Investment stimulus for new construction includes production tax credits and loan guarantees for technologies that reduce emissions. Some loan guarantees encourage private sector investment by providing insurance against delays during construction, to include licensing and litigation. The Energy Policy Act was not simply fiduciary; Congress was setting objectives to end foreign energy dependence, and nuclear was one of several technologies targeted. Policy emphasis concerning advanced reactor development was furthered with the Nuclear Energy Research Initiative Improvement Act of 2010 which requires the Secretary of Energy to carry out a research and development to reduce first of a kind costs related to small reactor design. The Nuclear Power 2021 Act requires Secretary of Energy to develop and demonstrate two SMR designs by 2020. DOE's FY2011 budget requested $39 million for the SMR program and congress raised it to $50 million (Welling, 2010). Although the 2020 objective is unlikely to be met, both Congress and the executive are engaged in advancing research and development for small and mini reactor designs while deferring some risk involved with first-of-a-kind technology. Energy Secretary Ernest Moniz recently stated that small reactors represent a new generation of safe, reliable, low-carbon nuclear energy technology, and the Energy Department is committed to help ensure continued leadership in the safe, secure, and efficient use of nuclear power worldwide (DOE, 2013).

DOE has managed these tasks under congressional intent and awarded numerous grants for research and development. Some of those pertinent to this discussion include:

- 2006-2010 Phase I, Next Generation Nuclear Plant was appropriated $528 million to advance Gen IV high temperature reactor designs for hydrogen production
- 2012 DOE SMR Licensing Technical Support Program formed to accelerate SMR deployment
- November 2012 DOE awards mPower group up to $226 million to advance iPWR design
- November 2013 DOE awarded a two year grant for Gen4 Energy to continue development of natural circulation designs for advanced reactors utilizing a lead bismuth coolant
- December 2013 DOE awarded up to $217 million to help finance the design, certification, and commercialization of the NuScale small module concept

The Next Generation Nuclear Plant (NGNP) serves as an example of Congress and executive initial steps to develop advanced nuclear technology and associated regulatory framework. NGNP was formally established by the Energy Policy Act of 2005 to demonstrate the commercial viability of generating electricity and/or hydrogen with a high-temperature nuclear energy source (DOE, 2010). The NGNP project has two phases; Phase 1 includes the conceptual design and demonstration research, and Phase 2 moves the final reactor design through licensing to the construction of a demonstration plant. This demonstration project was to be the first advanced reactor licensed in the U.S. initiating a shift in nuclear energy from LWRs to Generation IV reactor designs. From 2006 – 2010, a total of $528.4 million was appropriated for the NGNP project to develop the designs for two different high-temperature gas reactors moderated by graphite and cooled using helium. Early versions of this reactor design were demonstrated in the 1970s and 1980s in the U.S. and are being tested in other countries, including Japan and China (DOE, 2010).

In 2011, the Idaho National Lab (INL) submitted an update on the accomplishments of Phase 1 activities to the Secretary of Energy for review, and to seek Phase 2 funding. On October 17, 2011 the

Secretary of Energy forwarded a letter to Congress concluding that, “given current fiscal constraints, competing priorities, projected cost of prototype ($4 billion), and the inability to reach agreement with industry on cost share, the Department will not proceed with the Phase 2 design activities at this time” (INL, December 2011). Although the design activities have ceased, the DOE and INL are continuing with limited research and development actions, including responding to NRC’s Requests for Additional Information. Their intention is to keep pre-application licensing activities going, such that if and when the NGNP is re-started they will remain up to date with the NRC.

DOE formed the small reactor licensing technical support program in 2012 to accelerate deployment of small and mini reactors by supporting certification and licensing requirements for US based projects. A $452 million multi-lend program was presented as a 6-year effort. Fiscal Year 2012 appropriations were $67 million and FY 2014 request was $70 million (DOE, 2013). The loan program’s first commitment, announced in 2012, went to Babcock & Wilcox, Tennessee Valley Authority, and Bechtel, awarding up to $226 million to advance the mPower integral pressurized water reactor (180 MWe). A few of the key activities outlined by DOE stipulate that mPower group submit a design certification to NRC by late 2014, initiate site characterization at TVA’s Clinch River Site, and construction permit applications to NRC by mid-2015.

Under a second funding opportunity NuScale Power was awarded up to $217 million which was formalized in May 2014. The contract represents a “five-year cost-share agreement. DOE will invest up to half of total project cost, with the project industry partners matching this investment by at least one-to-one(DOE, 2013).” In this case Fluor is the primary corporate investor for NuScale, and Fluor’s investment capital must be equal to or greater than the federal contribution to NuScale. Further, DOE states the investment may help NuScale obtain NRC design certification to achieve commercial operation around 2025. Key activities expected to be honored in the agreement include completing preliminary test by the first quarter of 2015, submit design certification application to NRC by second half of 2016, and complete primary system design by the end of 2018.

2.4.3 Alaska

Beyond policy enacted at the federal level, Alaska has crafted its own regulations that are important to consider for nuclear facility siting in the state. In 2010, the Alaska Legislature passed SB 220, also known as the Alaska Sustainable Energy Act. The Omnibus Energy Bill was intended to modernize AK statutes, clarify jurisdictional responsibility, put nuclear on a level playing field with other alternative energies, and remove gubernatorial approval of facility siting permits. Specifically, AS 18.45.025(b)(1) is amended to give the Legislature the authority to designate lands in the state for the use of nuclear utilization facilities provided they act in the interest of regulating the economics of nuclear energy (Kane, 2010). Previously, this passage stated that the legislature had the authority to act in the interest of public health and safety in designating lands, but prior court cases, *Northern States Power Co. v Minnesota* and *Pacifica Gas & Electric Co. v. State Energy Resource Conservation & Dev. Comm'n*, established that the authority to regulate public health and safety of nuclear rests solely with the NRC. Accordingly, the state is only allowed to preclude a site from use by a nuclear facility if it is not in the economic interest of its citizens.

The other significant component of this bill qualifies that a person may not construct a nuclear facility in the state without first obtaining a permit from the Alaska Department of Environmental Conservation (ADEC). This permit, if the proposed site was located in a municipality, would require municipal approval before it could be issued. According to the staff at ADEC, although the Act mandated the creation of an authorization program, funds have yet to be allocated for the development of one. Further, ADEC states that nuclear facility proponents would first have to go through the entire NRC permitting process before there could be a local one. If an application for an ESP or COL was submitted for a location in Alaska, the legislature would then need to appropriate the funding for the state authorization program (Mendivil, 2014).

Collectively, nuclear regulatory frameworks are well defined for the existing commercial fleet. Many advanced nuclear power designs are modifications to existing commercial technology with precedent. Similarly the framework governing the current fleet must be modified in order to accept new reactor designs. Senator Lisa Murkowski-AK, currently a ranking member assigned to the Committee on Energy and Natural Resources, released a plan called Energy 20/20 in February 2013. The report stipulates that energy and natural resource policies must be re-imagined. "America's energy infrastructure has aged, the price of oil is high, and the challenge of ensuring reliable and secure energy supplies has never been greater (Murkowski, 2013)." Energy 20/20 refers to nuclear power as one of the most reliable sources of baseload electricity, one of the cleanest sources of energy, and a source of good-paying jobs (Faibish, 2014). Senator Murkowski's report outlines many actions capable of addressing energy infrastructure improvements by defining initiatives put forth in the Energy Policy Act, and offers Gen III + and Gen IV reactor designs as one factor contributing towards national energy independence.

Chapter 3 Advanced Nuclear Power

Gen III+ and Gen IV small nuclear power plant vendors anticipate emerging in the US commercial energy sector within 10 years. The Gen III+ integral pressurized water reactors are the most mature of these technologies and domestic designs are usually associated with companies such NuScale, Babcock & Wilcox, and Westinghouse. The market in small and mini reactor technology is not wholly domestic, in fact the first advanced design proposed in Alaska was Japanese; Toshiba 4S. The KLT-40S and CAREEM small power plants are reportedly under construction in Russia and Argentina respectively (IAEA, 2012) (Nuclear Future, 2013) (Nuclear Future, 2014). These international reactors will be introduced along with their domestic counterparts to evaluate technological designs with potential application to the Alaskan energy market. An international design must conform to US regulatory process even if certified in their respective country; therefore, technological maturity of a foreign design does not equate to accelerated approval from NRC or entry to the US market.

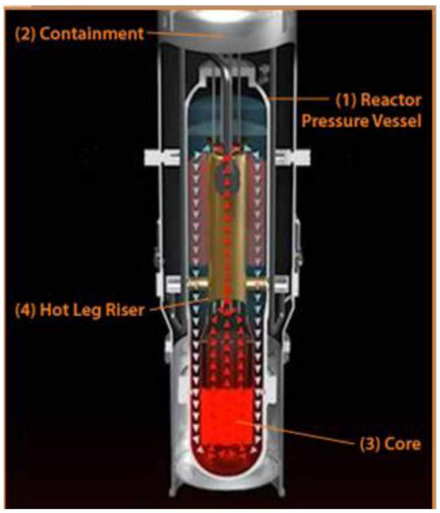
3.1 Gen III+ (NuScale, mPower, KLT-40S, and CAREM)

A Gen III+ small reactor design integrates the steam generators, pressurizer, control rod drive mechanisms, and reactor coolant pumps into the reactor pressure vessel; referred to as an integral pressurized water reactor (iPWR) (Power, 2010). This eliminates the need for piping between pressure vessels and steam generators which greatly reduces demands on the containment structure (Vujic, et al., 2012). Both Gen III+ and Gen IV reactors incorporate a passive design to safeguard against external mechanical failure of a pumping system. This passive design utilizes natural convection as a safety feature. Natural convection of the coolant fluid ensures decay heat continues to be removed from the reactor core in the event of sudden or unexpected reactor shutdown. Gen III+ iPWRs are often promoted as a small modular reactor (SMR). Modular emphasizes the incremental or multi-unit approach towards iPWR. SMR vendors envision delivery of a single modular plant with incremental deployments, allowing the first unit to come online with follow on construction of additional units (Halfinger, 2012).

3.1.1 NuScale

The NuScale nuclear power plant design is rated with a thermal output of 160MWt and electrical output of 45 MWe. The fuel assembly is a modified 17 x 17 pressurized LWR commercial design and utilizes uranium oxide (UO_2) at less than 5% enrichment. The fuel cycle is estimated at 24 months before refueling with a total vessel life of 60 years (IAEA, 2012); approximately 30 fuel cycles. The nuclear core is cooled entirely by natural convection during operation. Decay heat increases temperature of the light water coolant which reduces its density. The change in density distributed over elevation creates a buoyant force and upward flow in a closed loop. (Liu & Fan, 2014). The NuScale design minimizes the number of primary coolant penetrations through the reactor vessel and maximizes the elevation of all reactor vessel penetrations. This allows for a large reactor core coolant inventory, while maintaining a low core power density (Halfinger, 2012). The reactor vessel has seven layers of barriers between fuel and environment to militate against radiation release.

NuScale, an Oregon based company, is majority owned by Fluor Corporation. In May 2014, NuScale finalized its agreement with the Energy Department for a 50-50 cost share up to $217 million.



In an effort to meet requirements set by the DOE lend program, an application for design certification is planned for late 2016. In June 2014, Fluor and NuScale announced a new joint office in Idaho Falls, ID promoting their first planned project and partnership with Energy NorthWest and Utah Associated Municipal Power Systems. Collectively, their goal is to build 12 SMRs linked together; generating 545 MWe in the desert west of Idaho Falls by 2023 (NuScale, 2014). The NuScale reactor is anticipated to measure 65 feet tall x 9 feet in diameter and a schematic of this design is shown in figure 5.

Figure 5: NuScale Reactor (NuScale, 2014)

3.1.2 mPower

Babcock & Wilcox (B&W) mPower is a Gen III + iPWR designed to operate at 530 MWt/180 MWe. Fuel assemblies are a modified version of commercial 17 x 17 design, and consist of UO_2 at less than 5% enrichment. Fuel life is estimated at 48 months with a total vessel life of 60 years; approximately 15 fuel cycles. The refueling process requires discharge of spent fuel which is replaced with new fuel (Halfinger, 2012). During normal operation the reactor core is cooled by light water with forced circulation driven by eight internal coolant pumps (IAEA, 2012). During a transient event, removal of decay heat from reactor core occurs by natural convection to ensure the core reaches a subcritical state.

The mPower design initially appeared as a leading contender among SMR vendors and was awarded the first contract under the DOE lend program. $79 million was allocated to the mPower group upon signing the formal agreement in April 2013 with an additional $20.5 million allocated in August 2013 (Department of Energy, 2013). However, in November 2013, Babcock & Wilcox issued a press release seeking additional equity partners for its mPower program, but to date has not reported any buyers. In April 2014, B&W announced restructuring of its small reactor program to include layoffs and funding cuts which were carried out in June. Funding for mPower was projected to be cut by 75% (Babcock & Wilcox, 2014). The DOE stipulated key activities for B&W to begin by end of 2014, but it is unclear if mPower will meet these deadlines.

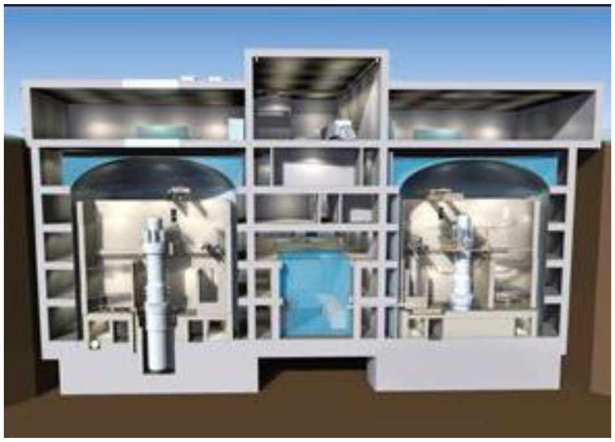


Figure 6: mPower modules (Generation mPower, 2012)

Both mPower and NuScale designs are subterranean which meets goals of radiation shielding and ensure appropriate measures considering non-proliferation. In addition, there is improved seismic capability as it is housed underground with geotechnical engineering advancements greatly enhancing the ability of a system to withstand earthquakes (Rosner and Goldberg, 2011).

3.1.3 KLT-40S

The KLT-40S is a pressurized water reactor with a capacity of 150 MWt/35 MWe. At project completion, a two-module unit will serve as a floating nuclear power plant capable of delivering process heat and electricity. OKBM Afrikantov of the Russian Federation designed these reactors based on a previous commercial marine propulsion plant (KLT-40). The specifications include: light water coolant under forced circulation in a pressurized vessel, UO_2 fuel enriched at less than 5%, and a refueling schedule of three to four years with a total vessel life of 40 years (IAEA, 2012).

Unlike other reactors, these ship-based units are constructed at a shipyard, and delivered fully operational to a coastal entity. Once moored, it does not require additional infrastructure associated with land based plants. Construction of the 472ft vessel Akademik Lomonosov began in 2007 and launched in 2010. Both reactors have been reported installed on the Akademik Lomonosov (Nuclear Future, 2014), but no further reports of operational status are currently available.

Figure 7: KLT-40S (OKBM Afrikantov, 2010)

Once complete, the promoters of the floating nuclear power plant with two KLT-40S modules claim it will produce "enough to provide electricity, heat and desalinated water to a city of 200,000 people (OKBM Afrikantov, 2010)."

3.1.4 CAREM

The Central Argentina de Elementos Modulares (CAREM) design is an integral pressurized light water reactor with capacity to generate 100MWt/25 MWe. UO_2 fuel is enriched at 3.1% with a fuel cycle of 2 years. Similar to the NuScale design, the vessel life is rated at 60 years and natural circulation of coolant occurs during primary operation (Nuclear Future, 2014).

This project began by modifying a German design reactor from Argentine Navy TR-1700 class submarines. Site excavation for the 25 MWe design was completed in 2012, construction began in February 2014, and total project completion is estimated at 2017 (World Nuclear Association, 2014) (Nuclear Future, 2014). CAREM is the first land-based iPWR under construction in the world. The 25 MWe CAREM is a prototype and once the design is proven, a larger (100-200 MWe) is planned for construction in Formosa, northern Argentina.

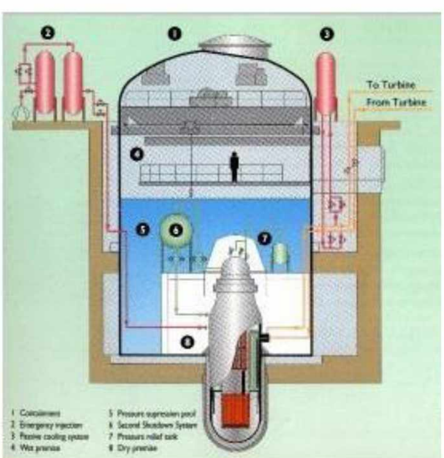


Figure 8: CAREM vessel (Comision Nacional de Energia Atomica, 2013)

3.2 Generation IV

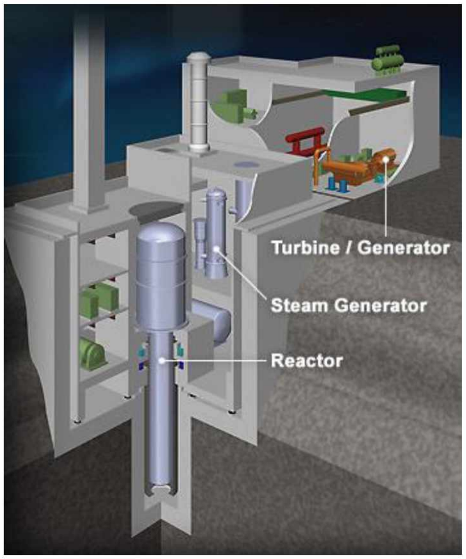
Gen IV mini reactor designs depart from the traditional water reactor design incorporating gas, lead/lead-bismuth, or molten salt as cooling fluid. Liquid metal cooled reactors will be discussed to compare against Gen III+ technology. Examples include two reactors that have been publicly offered for separate Alaskan communities, 4S and G4M. These mini reactors are promoted as single units; not scalable. Designs for stand-alone reactors range from 3 to 100 MWe, but tend to be less than 45 MWe. The Gen IV reactor is intended to fill a previously unmet remote energy niche to include civilian, military, and industry clients.

Stand-alone reactors are factory-sealed, non-refueling individual units transported to a site for operation. The individual unit is replaced with an entirely new power module after its useful lifetime. Recall, the iPWR vessel would be refueled in 2-3 year increments over a period of up to 60 years. Fuel cycle is a function of the uranium enrichment. iPWR generally utilizes uranium enriched at 3-5%. Commercial reactors may only utilize low enriched uranium; defined as less than 20% enrichment. In order to achieve a longer fuel cycle, Gen IV mini reactors require uranium enrichment at near 20%. The Gen IV reactor design maximizes uranium enrichment to provide a fuel cycle lasting for the rated life of the vessel; 10-30 years.

3.2.1 4S

Toshiba developed a liquid metal cooled fast reactor called the Super-safe, Small and Simple (4S) reactor. The 4S is designed to provide 30MWt/10MWe from a sealed, non-pressurized underground vessel. The reactor core is cooled with molten sodium under forced circulation and utilizes a Uranium Zirconium alloy enriched at approximately 19%. Toshiba reports the fuel cycle, thus life of the vessel, at 30 years.

The concept of 4S in Galena materialized in 2003 as the former city manager, Marvin Yoder, considered alternatives to traditional hydrocarbon power plants in an effort to lower energy costs. In 2004, Toshiba presented 4S at the Alaska Rural Energy Conference and the DOE funded an economic analysis of the proposed project (Alaska Center for Energy and Power, 2011). Initially the 4S unit was to be free if the customer paid for licensing, but that arrangement evolved over the next few years where Galena would absolve costs for the vessel as well as permitting and the project became fiscally unsustainable. In 2009 Toshiba announced intentions to submit the 4S to the NRC for design certification, which did not materialize, but technical reports were delivered to the NRC in 2010.

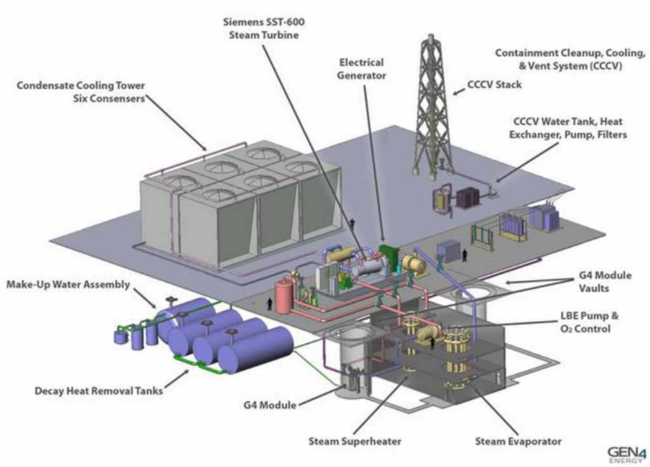


Additional technical reports were provided to NRC in February, 2013 but NRC notified Toshiba in March, 2013 that it will not review this technical report of its liquid metal-cooled reactor design due to resource constraints (Nuclear News, 2013). Talks with Galena are not continuing today however Toshiba reports that design and research of 4S continues at the Central Research Institute of the Electric Power Industry in Japan.

Figure 9: 4S Power Plant (Toshiba Corporation, 2014)

3.2.2 G4M

The Gen4 Module (G4M) is a conceptual design first conceived at Los Alamos National Laboratory to fill a previously unmet need for a sustainable, transportable power source. The plant design delivers 70MWt/25MWe utilizing a lead-bismuth cooled reactor (IAEA, 2012). Fuel consists of 19.75% uranium nitride and fuel cycle is estimated at 10 years, no refueling. Lead-bismuth removes decay heat from the reactor core under forced circulation. Two passive designs remove decay heat from the core during an operational shutdown. The first is natural circulation of the coolant in primary and secondary loops. Passive vaporization of water from the surface of the secondary containment vessel is the second (Zhang et al. 2013).



The Gen4 Module was reportedly being considered for development at Ester, AK in 2010. Gen4 Energy was founded as Hyperion Power Generation Inc. in 2007, and renamed in March, 2012. Talks in Ester for a Gen4 Module did not progress beyond ideas and was comparatively less structured than the Galena prospectus; however, the initial vendor promotion was intriguing.

Figure 10: G4M conceptual drawing (G4 Energy, 2013)

They compared the G4M to Aurora Energy power plant, saying the power output for both plants are roughly the same, but G4M is compact, sealed, and buried underground (Rettig, 2011). Small footprint is often promoted with these advanced reactors, which is verifiable based on fission releasing 10^6 more energy than combustion. Although, the vessel should not be considered wholly independent as ancillary structures and exclusion zones for safety, operations, and security would exist in any scenario.

The G4M project was awarded a grant from DOE in 2013 to continue research in lead-bismuth natural circulation to remove decay heat from the reactor in the event pumping power is lost to the reactor core. Gen4 Energy is collaborating with Massachusetts Institute of Technology, University of South Carolina, Los Alamos and Idaho National Laboratories during the two year grant (DOE, 2013). The G4M grant was one of four projects selected by the Energy Department. A total grant of $3.5 million was distributed among the awarded projects. DOE stipulated that all grant monies must be met with a 20% private cost share. The other project awards focus on a variety of Gen IV designs improvements. General Atomics will research silicon carbide material for fuel rod cladding, GE Hitachi Nuclear Energy will help design electromagnetic pumps for liquid metal cooled reactors, and Westinghouse will conduct analysis on sodium thermal hydraulics (DOE, 2013).

Gen IV commercial vendors promote energy solutions for remote mining or oil and gas operations, large government complexes, and isolated and islanded communities. Vendors of these mini reactors are also likely to promote no on-site refueling, and the elimination of intermediate storage facilities as compared to the light water reactors. However, no Gen IV reactor design is anticipated to precede the Gen III + iPWR to market. The technology of iPWR is more progressed, mainly because of the similarity to the advanced light water design of the existing commercial fleet.

3.3 Process Heat and Co-generation

Advances in nuclear energy are coming not only in the technology, but in the potential uses that can increase its marketability. Many proponents point to the potential benefits of co-locating nuclear technology with renewable resources, such as wind and solar, and/or process heat applications to take direct advantage of thermal energy. Integrated energy systems could be used to enable higher penetration of renewables onto the electric grid while creating an opportunity to produce revenue from product streams beyond thermal energy base load, such as food processing, greenhouses, or industries of mining, oil and gas. This section will introduce concepts of process heat applications and the developing vision of a nuclear hybrid energy system.

3.3.1 Process Heat Applications

Nuclear fission is a heat intensive process producing nearly three-times as much thermal than electric energy. 80% of Alaskan energy consumption is thermal and there are potential opportunities for small and mini reactors to facilitate a portion of this thermal requirement. Even during normal electric generation, excess heat may be recycled toward various low temperature range applications such as fish processing, greenhouses, district heating, and desalination. Small and mini reactors may be modified to primarily contribute heat at a high temperature range to meet industrial or infrastructure needs. Figure 11 shows temperature requirements for various process heat applications. Reactor core outlet temperature is a function of heat transfer from fuel matrix to coolant. Gen III+ iPWR and Gen IV designs being discussed report approximate core outlet temperatures of 325°C and 500°C respectively.

Application	Temperature Range (Celsius)
Fish Processing	30-50
Greenhouse	45-50
District Heating	30-80
Desalination	30-130
Biomass to Biofuel	200-500
Oil Production	500-600
Coal to liquid fuels	800-900
Hydrogen Production	800-1000

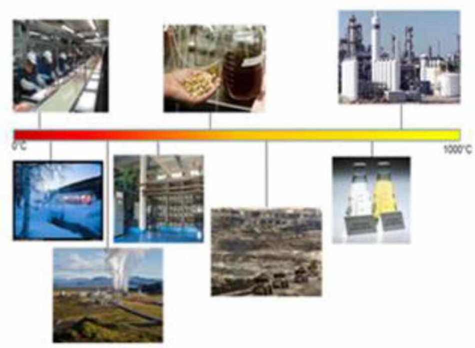


Figure 11: Temperature requirements for various process heat applications

A primary opportunity to utilize process heat in Alaska is through steam or hot water. District heating is a method of distributing thermal energy via underground piping to buildings and residences thereby alleviating electric demand and associated efficiency losses. Large scale interior applications include Fort Wainright and Eielson Air Base, which both distribute steam for heating. In 2009 Eielson required 340,000 pounds of steam per hour to meet peak heating periods. The Auroa power plant in Fairbanks utilizes steam and hot water district heating for select downtown business and residences. Several international examples of district heat infrastructure expansions are available for review. About ten percent of power produced by Russian nuclear plants provides district heating, and is expected to increase to over thirty percent as their designs mature (World Nuclear Association, 2014a). Iceland (geothermal) produces 1,380 MWt for district heating, and 200 MWt for snow melting (IGA, 2014) greatly reducing demand for electricity production. District heating provides a thermal baseload for residences and workspaces, but may also be utilized to increase production rates in certain industries.

Greenhouses are able to appreciate longer growing seasons with district heating. Kawerau's greenhouses (geothermal) in Auckland, New Zealand, have been using steam district heating since 1982. Other low temperature applications involve aquaculture and food processing. Iceland utilizes 67 MWt for fish farming and associated processing, providing additional food to the local market and jobs to the community (IGA, 2014). Maple Lodge Farms in Ontario uses 4 million pounds of steam and 125 million gallons of hot water annually during poultry processing operations (SOFAME, 2003). Warsteiner Brewery in Germany uses 2.3 MWt in their daily operations at the brewhouse.

Any of these low temperature (up to 300°C) domestic or industrial applications may be facilitated with the Gen III+ iPWR. Associated infrastructure is required to develop district heat projects in Alaska. In some instances, existing infrastructure could be expanded to benefit more customers such as Fairbanks and surrounding military bases. In addition, some remote Alaskan communities may already have the necessary infrastructure to be compatible with district heating. In Kiana, large riverbank wells provide the public water supply, which is distributed to the community via buried water mains. More than 92 percent of Kiana households are connected to the water lines, as is the health clinic, school and community hall.

Desalination, removing salt and other minerals from saline water, accepts a wide variety of heat inputs, ranging from reverse osmosis on the lower end to multi-stage flash distillation on the higher end. Integrated desalination facilities with nuclear power plants have been proven feasible chiefly in Kazakhstan, India and Japan. For example, the low temperature nuclear desalination plant uses waste heat from the research reactor at Trombay in Mumbai, India (World Nuclear Association, 2014b). The small ABV-6 reactor in Russia is rated at 38 MWt, producing 12-18 MWe and 40,000 $\frac{m^3}{day}$ of potable water by reverse osmosis. These same processes could be applied to water purification to benefit any number of remote communities to meet Safe Drinking Water Act requirements (Christian, 2007).

Other industrial applications for middle temperature (300-500°C) ranges include biofuel and shale oil production. Gen III+/Gen IV could provide the thermal energy required to convert biomass to biofuel; however combustion of byproduct gases continues to be more efficient and effective in the operations of pyrolysis (European Commission, 2014). This becomes another evaluation of market competitiveness, and biofuel does not appear a likely candidate for early thermal applications in Alaska.

The production of oil shale requires a multi stage process utilizing low and medium range temperatures; 100 to 350 °C (American Shale Oil, 2011). Sunshine Oilsands Ltd. (Calgary) estimates steam temperatures between 300 and 400°C. The Toshiba 4S has been promoted for the application of the Canadian Oil Sands (Arie, 2009).

Synthetic and unconventional oil production, as well as oil refining, becomes feasible with higher core outlet temperatures of 700°C. Hydrogen may be produced for fuel at temperatures of 800°C and greater. These high temperature applications are usually reserved for specialized Gen IV reactors. Recall the NGNP project was a Gen IV reactor attempting to achieve hydrogen production. These high temperature heat applications require maturation of Gen IV reactor designs (15+ years) before potentially discussing for Alaska.

3.3.2 Cogeneration

Cogeneration is a developing concept of integrating multiple alternative energy sources for grid distribution, and is being promoted as a pathway to reduce carbon production in the energy sector. The Gen III+ iPWR is a strong candidate in cogeneration models. Essentially, nuclear provides a reliable baseload energy requirement while other sources such as solar or wind assist with peak demand; potentially enabling load following. There is quite a bit of electrical engineering to consider because multiple producers must be integrated into one consistent electric source before being distributed to the grid.

The most intensive cogeneration economies in the world are Denmark, the Netherlands and Finland. In 2013, forty-five percent of Denmark's electricity was produced through cogeneration, more than thirty-five percent of Finland's electricity, and more than thirty percent of the Netherlands' (Kiss, 2013). Forty-four percent of the heat supply used in Russia's centralized heating systems is produced by cogeneration (Roshchanka, 2012). Industrial sectors which have expanded to include combined heat and power include agriculture, car manufacturing, paper, health care, and sewage treatment.

One significant advantage to industrial cogeneration is this: A reliable baseload may be maintained while removing individual subsystems for maintenance, thus creating a diverse and more resilient energy infrastructure. Industries with smaller capacity and thermal storage could take on an important role in providing demand response, flexibility, capacity and balancing. Further, the potential to integrate renewables with small reactors offers a flexible operation with the ability to accommodate multiple non-hydrocarbon energy providers into one grid.

Prior to the co-location of nuclear reactors with other facilities, siting issues will have to be addressed with the NRC, as there are presently no governing regulations (Mays, 2014). Among the issues to be considered would be the ability to define a clear boundary between the reactor and other facility to ensure the reactor is not dependent on, or adversely affected by, events that occur within the separate industrial facility (INL, July 2014). This plant area boundary is also important to delineate in order to clarify the components and systems that NRC has jurisdiction over, and which would be under the guise of the other system's regulator. Lastly, when considering applications such as chemical processing facilities, respective buffer zones and exclusion area boundaries may need to be adjusted, or worked around in order to safely operate.

Chapter 4 Future Framework Opportunities and Barriers

Thus far, the update on the commercial availability for small and mini reactors has focused on the status of the technology and the policies underway to facilitate maturation. Next will begin a review of why regulators and experts in the nuclear industry speculate the first commercial iPWR will be in operation between 2022 and 2025. To be included here are the potential opportunities and barriers in the regulatory sector, economics, public perception, and environment.

4.1 Regulatory

As the technology brief has demonstrated, the U.S. nuclear power fleet is predominantly based on light water reactor designs. These systems, with an average output of 1000 MWe, require complex control systems to handle operation, and can be vulnerable to potential radionuclide release specific to complications of water as a coolant (Fehrenbacher, 2010). Accordingly, the NRC has crafted its regulations and metrics for safety evaluation to be based upon the features and design basis events of these reactors. Some of the mechanisms conceived of by the NRC to provide adequate safety margins appropriate for light water reactors do not necessarily translate to the systems of advanced reactors, making their licensing or economics impractical. Similarly, there may be safety concerns posed by advanced reactors that are currently not examined in NRC regulations.

This issue can be illustrated by looking at the current rules governing operational staffing for nuclear power plants and the use of Core Damage Frequency as a metric for design basis events. Under the staffing requirements in 10 CFR 50.54(m)(2)(i), shown in Figure 12, a single-unit 10 MWe reactor plant is required to maintain four licensed operators per shift on-site. Four on-shift operators translate into a combined operating staff of 40 to 80 personnel. With many current SMR designs utilizing passive safety systems, integrated components, and fewer dependencies, there is much less need for operator intervention under normal operation or accident response; therefore, the staffing requirement does little to improve safety while raising operational costs (American Nuclear Society, 2010).

Minimum Requirements[1] Per Shift for On-Site Staffing of Nuclear Power Units by Operators and Senior Operators Licensed Under 10 CFR Part 55

Number of nuclear power units operating[2]	Position	One unit	Two units		Three units	
		One control room	One control room	Two control rooms	Two control rooms	Three control rooms
None	Senior Operator	1	1	1	1	1
	Operator	1	2	2	3	3
One	Senior Operator	2	2	2	2	2
	Operator	2	3	3	4	4
Two	Senior Operator	....	2	3	[3]3	3
	Operator	....	3	4	[3]5	5
Three	Senior Operator	....	....	....	3	4
	Operator	....	....	....	5	6

Figure 12: Licensed Operator Requirements under 10 CFR 50.54 (m)(2)(i)

Source: http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol1/pdf/CFR-2011-title10-vol1-sec50-54.pdf

Core Damage Frequency (CDF) is the sum of the frequencies of accidents that result in uncovering and heat-up of the reactor to the point at which prolonged oxidation and severe fuel damage involving a large fraction of the core is anticipated. This deterministic source term is used to evaluate the release mitigation effectiveness of engineered safeguard systems, such as containment and ventilation (NRC, December, 2007). For example, in a Station Black Out, a plant experiences a total loss of electric power, preventing the operation of the mechanical pumps keeping the reactor core cooled. Without the successful use of back-up generators to restart these systems, this can lead to a core damage event. The NRC prefers to use CDF as a risk metric because it is one of the principle events that can result in radiation exposure to the public, and can be the result of system failures or even outside events. In the case of many non-traditional designs, inherent or full passive safety features depend only on physical phenomena such as convection, gravity or resistance to high temperatures, not a function of mechanical components. Accordingly, CDF may no longer be an applicable metric to gauge the safe operations of the reactor.

4.1.1. New Regulations & Exemptions

Given the regulatory focus on light water reactors, those planning to develop Generation IV technology may seek for the NRC to develop a new set of technology neutral regulations that could provide a licensing pathway for advanced reactors. The NRC, as an independent regulatory body, may elect at any point to craft a new set of regulations, or can be compelled to do so by the directive of Congressional legislation. Regardless of the impetus, this strategy presents an inefficient option as historically even minor changes to existing regulations have taken several years. For example, a proposal to remove hydrogen re-combiners from the design basis of pressurized water reactor containments, a notion widely agreed to be of little safety significance, took from 1992 to 2003 to receive final approval (American Nuclear Society, 2010). The complex undertaking of drafting an entirely new body of regulatory controls and safety standards could potentially take several decades.

Another option for licensing advanced reactors would be the use of the exemption clause codified in 10 CFR 50.12. Under this, nuclear power plants may seek an exemption from otherwise applicable requirements if "(1) the requested exemption is authorized by law, will not present an undue risk to public health and safety, and is consistent with the common defense and security and (2) special circumstances are present that warrant the granting of the exemption" (NRC, July 2014b). Exemptions have frequently been granted for minor design differences requiring minimal examination of secondary impacts; nonetheless, the potentially complex and numerous exemptions sought by non-LWR reactors designs could stretch this system beyond its usable bounds. As the American Nuclear Society points out, requesting several exemptions for one reactor would require a significant amount of effort on the part of the NRC and the applicant to demonstrate that the combined result of these minimal effects would not cumulatively be significant. Further, there may be negative public perception of a reactor seeking multiple exemptions, which could lead to hearings and litigation that delay the project and raise costs.

4.1.2. Risk-Informed Performance-Based Licensing

A third, and perhaps most realistic, avenue for licensing advanced designs is a Risk-Informed Performance-Based (RIPB) approach. RIPB is an adaptation to current regulations that applies a review process emphasizing outcomes rather than prescriptive means for achieving them, thus providing more design flexibility. Under this system, technology specific metrics, such as CDF, are replaced with performance metrics that get at the heart of why CDF is a concern, namely dose exposure to the public. In this way, safety analysis and regulatory oversight can focus on those items most important to safety for that design, while avoiding the time consuming and less predictable process of reviewing non-LWR designs against LWR-oriented regulations (NRC, December 2007).

RIPB is based on Probabilistic Risk Assessment (PRA), a licensing device that has been employed by the NRC since the Three Mile Island incident of 1979. In PRA, risks are addressed as they relate to the performance of complex systems to understand likely outcomes, sensitivities, areas of importance, system interaction, and areas of uncertainty (NRC, December 2007). Although a part of the NRC safety review, PRA has been treated as separate from the deterministic calculations carried out for the licensing basis events, which are the postulated accidents that a nuclear facility must be built to withstand. In the RIPB approach, PRA analysis is linked with the licensing basis event selection, design criteria, and structure, system, and component (SSC) selection and treatment (NRC, December 2007).

RIPB is a more comprehensive approach to addressing the risk triplet. What can go wrong? What are the consequences? How likely is it? Under the current deterministic system, the NRC addresses the first two questions by providing a set of postulated accidents based on LWRs, which designers use to explain how their reactor would respond to and operate safely. Using RIPB, the question of frequency is incorporated into the selection of the licensing basis events, allowing regulators to focus safety standards on incidents that would have potential impacts on the specific design. In order to facilitate this evaluation, those working on the NGNP project, a High-Temperature Gas Reactor requiring a new licensing strategy, created a Frequency-Curve, shown in Figure 13. This allows events to be plotted according to the likelihood of their occurrence per plant year (y-axis) and the dose level to the public that could be expected (x-axis). This risk-informed event selection is complimented by deterministic engineering judgment and analysis, as well as the NRC's adherence to defense-in depth and protection strategies.

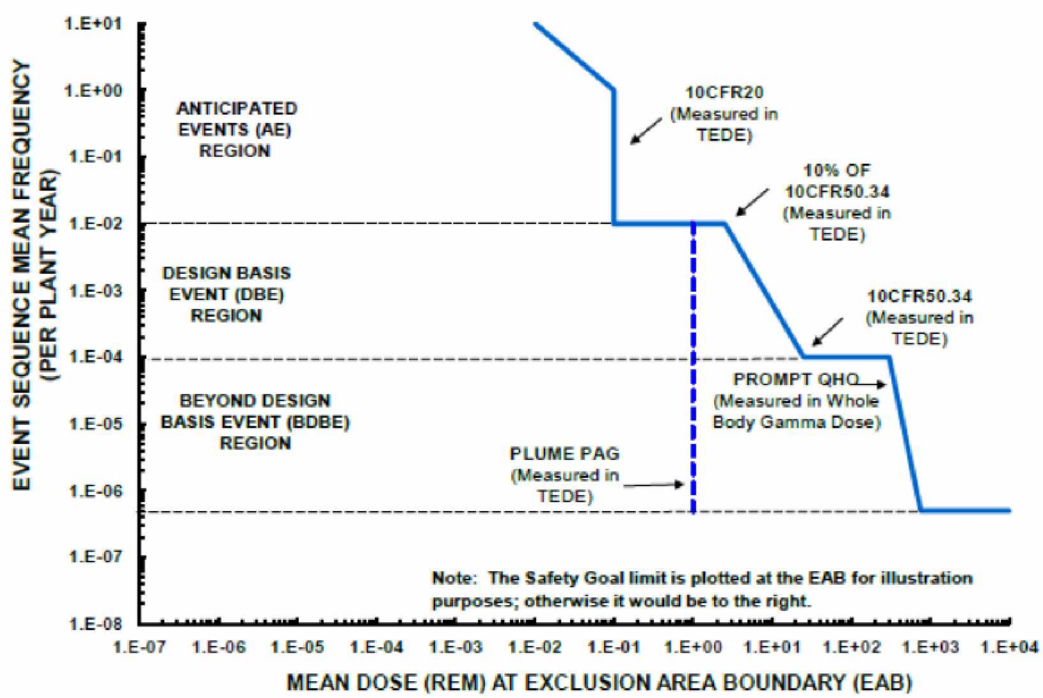


Figure 13: NGNP Frequency-Curve (NRC, March 2011)

4.1.3. Design Criteria

In addition to augmenting the licensing basis event selection to be compatible with advanced reactors, the DOE and NRC agreed in 2013 to work together to develop adaptation language for the General Design Criteria of nuclear power plants. Found in 10 CFR 50 Appendix A, General Design Criteria establishes the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety (NRC, July 10, 2014c). There are currently three drafts for these guidelines: one that is technology neutral, one with a High-Temperature Gas Reactor focus, and one specific to Sodium-Cooled Fast Reactors. Workshops took place in April and July of 2014 to review these drafts, but no ruling has been made yet by the NRC on whether these parameters will be acceptable going forward (Kinsey, 2014).

4.1.4. RIPB Implementation

The NRC officially began discussions about the adoption of a RIPB approach in Yellow Announcement #019 released March 11, 1999. This document stated; "the Commission is advocating certain changes to the development and implementation of its regulations through the use of risk-informed, and ultimately performance-based approaches" (NRC, December 2007). Following this statement, the NRC, along with the American Nuclear Society and Nuclear Energy Institute began a series of white papers and workshops to investigate how this system may operate and what would be the appropriate metrics to quantify proper performance.

Title VI, Subtitle C, Section 641 of the 2005 Energy Policy Act directed the DOE to develop the NGNP prototype for commercialization. As a part of this effort, the Energy Secretary and Chairman of the NRC were given three years to jointly submit a licensing strategy for the prototype (DOE, 2008). The conclusion of this licensing report is that RIPB would be the preferred path forward for commercialization of advanced reactors. Believing that the NGNP license submittal was on the horizon, NRC stated in SECY-07-0101 that they would defer a decision on rule-making for RIPB until the review of the COL of the prototype. This statement is in line with other documents subsequently issued that state the NRC will not rule on RIPB as a licensing strategy until they can pilot it with the specific design in a COL or DC application. NGNP was the prospective technology anticipated to undergo a dual licensing process. However, the decision to cut funding to the NGNP project created a vacuum for who would be the first design to take on the pilot process.

Presently, NuScale is most likely to begin the DC process for their reactor; however, as an integral Pressurized Water Reactor (iPWR), many of their features are similar enough to current technology that they will be able to utilize the existing licensing system. Some issues related to the modularity and operator staffing will need to be addressed (NRC is actively working with NuScale to separately address multi-modular risk and staffing in a series of workshops and public meetings), but it is in their financial interest to work within the current system rather than take on the piloting onerous of the new.

The reason the pilot process will be particularly costly is that the NRC wants the pilot of the RIPB to be carried out in tandem with a review of the design under the existing structure using exemptions, in order to compare the results of the analysis to be sure RIPB is as robust. Given the dual processes, the timeline for certification is estimated to take 7-8 years, instead of the approximately 4 years for current reviews. The cost of paying for both reviews, and the project management needed to keep on task for the doubled timeline, will most likely be the financial burden of the entity seeking the first such DC or COL. For these reasons, the first reactor design to undertake this will be an advanced reactor, one based on high temperature gas, sodium, or liquid metal, that may not receive regulatory approval another way.

Following the first-of-a-kind to pursue this strategy, the timeline and cost should go down significantly for other reactors. James Kinsey, Director of Regulatory Affairs for the NGNP project, estimates that RIPB draft regulations will be created in parallel with the pilot certification. In this way, the next designer interested in this strategy will be able to apply through it immediately following the first DC or COL issued using it. Furthermore, with the staff training gained through the pilot, certification timelines could be reduced for the second reactor to 4.5 – 5 years.

Some developers have expressed frustrations with the NRC about a lack of clarity on whether RIPB will be an acceptable licensing strategy. Although the NRC has reviewed and authored many reports on the subject, they are reluctant to provide guidance beyond that it seems like a reasonable approach. Furthermore, they are withholding whether a probabilistic design basis event selection will be sufficient for applicants, or if they will later include a deterministically chosen set to be analyzed as well. The NRC emphasizes that they are not in existence to license paper reactors. That as long as advanced reactors remain theories without actual customers, or the financial commitment of a COL or DC application, the NRC will not expend the time or resources to provide any more detailed regulations. From the designer's perspective though, it is difficult to obtain investor funding to file for a COL or DC when the licensing pathway is still unclear. In their 2012 *Advanced Reactor Licensing Report to Congress*, the NRC laid out an estimated timeline for when they see various advanced reactor technologies being able to be licensed based on the progress of R&D and NRC staffing efforts. This timeline is shown in Figure 14 below.

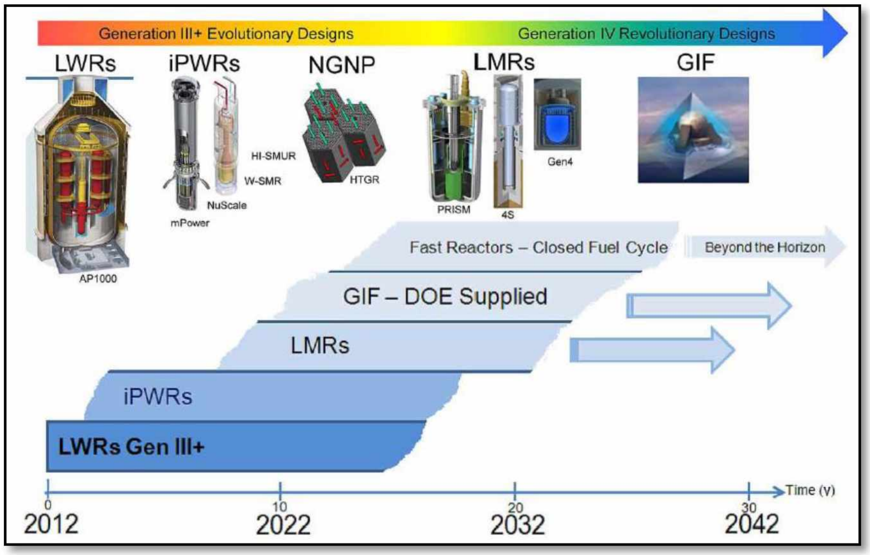


Figure 14: Potential Future Reactor Licensing (NRC, August, 2012)

4.2 Economics

For stakeholders exploring energy options, economic considerations are cornerstone to evaluating feasibility. This section presents appropriate economic models, examines the competitiveness of nuclear in the current market, and discusses other variables such as annual operation fees, and insurance requirements. Collectively, these examples illustrate factors to quantify for a true estimate of capital investments. The summation of these costs aid potential developers to determine economic feasibility of a new reactor project and its competitiveness in the state's energy sector.

4.2.1. LCOE

Developing a nuclear power plant is unique in the utility sector due to its significant up-front capital costs as compared to traditional hydrocarbon power plants; however, nuclear energy provides long term fuel cost stability. Reducing the size of a nuclear power plant enables the nuclear industry to compete in markets with small electric grids and remote locations. Lower capital for a small reactor means lower financial risks associated with their deployments. Reducing financial risk may allow smaller capital utilities to invest in Gen III+/Gen IV technologies. The potential to reduce its total land footprint and staffing may also add to fiscal appeal when considering initial acquisition and long term operation and maintenance costs. Material cost per kW increases as the power output decreases due to surface area per kW of capacity. This means small reactors are more expensive per kW as compared to large reactors. In order to overcome this financial obstruction, multiple modules are modelled in most economic analyses

Overnight capital cost represents the cost to manufacture, construct, and deploy the power plant in one day. There are two approaches toward estimating small reactor overnight capital cost; top down and bottom up. A top down approach utilizes known data from large reactors and reduces by a scaling factor to represent smaller output. However, scaling down commercial costs from a 1000 MWe in the lower 48 to Alaska at less than 50 MWe may induce significant error. The bottom up approach should be more representative of overnight capital cost for Alaska to consider construction and manufacturing at the plant and transportation to site for deployment.

The plant's capital cost is a required initial metric, but levelized cost of electricity (LCOE) is a more comprehensive measure factoring in capital costs, fixed and variable operating costs, construction, capacity factor, heat rate, cost of financing the project and decommissioning (Abdulla, 2013).

$$LCOE = \frac{\sum_{y=1}^{n}\left(\frac{I_y + OM_y}{(1+d)^y}\right)}{\sum_{y=1}^{n}\left(\frac{E_y}{(1+d)^y}\right)}$$

where:

n is plant lifetime

Iy is the investment cost in year y (initial and incremental capital)

OMy is the operating and maintenance cost in year y (fixed and variable)

d is the discount rate

Ey is the electricity generated in year (y)

Abdulla and Azevedo quantified these variables from expert elicitation and compared LCOE for a 45 MWe iPWR as an individual unit to a 5-module purchase for a total of 225 MWe. The single 45 MWe unit median estimate was $139 per MWh while the 5-module site would be less expensive at $124 per MWh. These findings are further associated with average electric prices in the US. States with average electric costs higher than LCOE include California, New York, Alaska and Hawaii at $130, $150, $160, and $290 per MWh respectively (Abdulla et al. 2013). They conclude that while cost savings will occur with additional module units, some geographic areas may still benefit from single module deployment. As mentioned, a vendor such as NuScale assumes a 4-6 module contract in its business model. The vendor's economic analysis, assuming incremental purchase, realizes benefits from economy of scale and usually incorporates a manufacturing learning factor, generally improving a project's cash flow and enabling smaller/local utilities to diversify their power generation portfolios (Halfinger, 2012).

The Nuclear Energy Agency - Organization of Economic Cooperation and Development (NEA-OCED) reviewed economics of small reactors (Kuznetsov & Lokhov, 2011). Specifically, they focus on the factors affecting competitiveness among various international small reactors. LCOE is calculated very similar to the above example; however, variables are quatified using vendor projections. Utilizing mPower cost data, NEA estimated the 125 MWe iPWR at a median cost of $47-95 per MWh. While this is not an exact comparison (NuScale 45MWe to mPower 125MWe), it illustrates that cost-benefit is more difficult to obtain as power levels decrease. For example, LOCE was also considered for the 4S (10 MWe) and estimated at $130-290 per MWh.

4.2.2) Market Competitiveness

In 2010 the Energy Department requested Argonne National Laboratory to examine economics of small reactors (50-300MWe) and initial findings of the study along with a business plan for deployment is included in a 2011 publication from the Energy Policy Institute at Chicago (Rosner & Goldberg, 2011). Their model assumes 12 modules (reactors) per year with continuous production of one module per manufacturer per month for 4 years with a total fleet of 48. The learning rate was 10% (FOAK 12 modules) distributed over 36 modules. The study concluded that continuous production under favorable conditions may allow the small reactor concept to compete against coal, oil, and natural gas. It was acknowledged that initial modules may not be competitive with natural gas combined-cycle generation and federal government incentives are needed to help overcome this barrier.

Perhaps the greatest impact to the solvency of nuclear power on the large utility scale is the dramatic shift in the price of natural gas. In 2001, rising prices of fossil fuels and discussions of a possible carbon tax created an economically favorable environment for a "nuclear renaissance". After seeing no new applications for a nuclear construction and operations license since the late 1970s, the NRC received proposals for thirty new reactors from thirteen different companies between 2007 and 2008 (Rascoe, 2012). Initial interest was emboldened by the 2005 Energy Policy Act that promoted nuclear construction through up to $2 billion in incentives and subsidies. As shown in Figure 15, by the summer of 2008 natural gas prices were as high as $13 per million Btu. This peak was short lived as advances in drilling techniques led to a domestic inundation of cheap natural gas, sending costs down to $3 per million Btu. These lower fuel costs are further compounded by the comparatively higher fixed costs at which nuclear plants operate, $90,000 per megawatt for nuclear to $15,000 for natural gas; and the fact that 40% of U.S. nuclear reactors sell power into deregulated markets (Smith, 2013). Dominion, operator of three nuclear plants in the U.S., has stated that due to the current economics "it would be cheaper to meet its obligations to nearby utilities with electricity bought on the open market than getting it from Kewaunee", a reactor it bought in 2005 (Smith, 2013). Moreover, the CEO of Excelon, one of the largest power producers in the U.S., expressed that for traditional nuclear plants to be viable natural gas has to cost at least $8 per million Btu with a tax on carbon of $25 per ton. Without the carbon tax, natural gas prices would have to be closer to $13 per million Btu (McMahon, 2014).

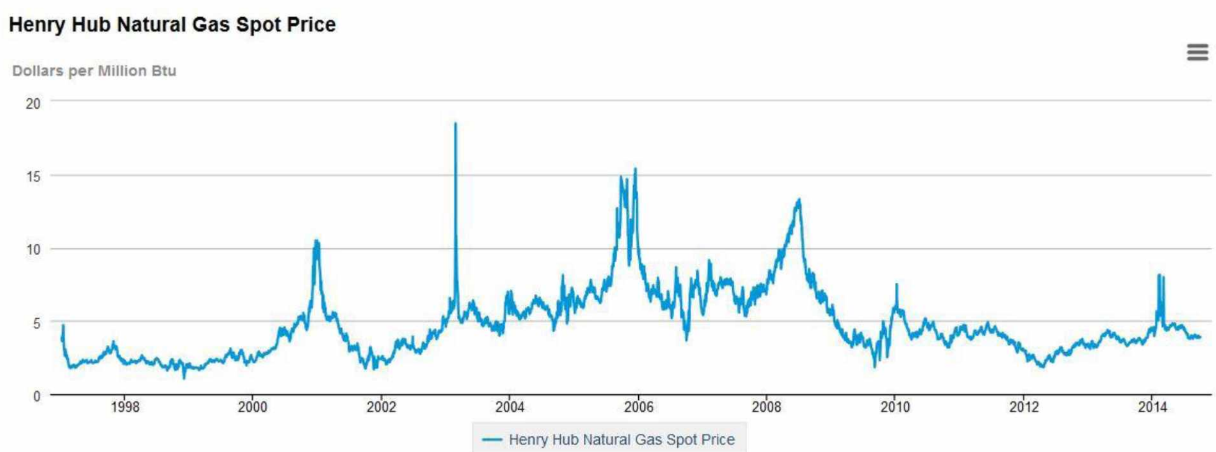


Figure 15: Natural Gas Spot Price; Source **http://www.eia.gov/dnav/ng/hist/rngwhhdd.htm**

Low costing natural gas may not be a major factor though when considering the viability of small reactors. Many of the customers that could benefit from them, such as remote communities and industry, may not have the infrastructure for natural gas, or be serviced by large utilities. Indeed, Excelon believes that although large reactors have a competitive disadvantage against other energy sources, there is still a future for nuclear energy in efficient modular reactor designs. If reactor vendors are able to make good on claims that a return on investment could be seen in two years due lower operating costs for safety and security, and manufacturing costs saved by standardized design, capital interest may facilitate production (McMahon, 2014).

4.2.3. Economic impacts of Fukushima

On March 11, 2011 a magnitude 9.0 earthquake, and subsequent 15 meter tsunami, stuck the east coast of Japan disabling the power supply and cooling function of three of the Fukushima Daiichi's boiling water reactors. Although emergency protocol caused control rods to shut down fission reactions, the continued release of decay heat without a functioning cooling system pushed the Generation II reactors into meltdown. The severity of this meltdown ranked as a Level 7 on the International Atomic Energy Authority's Nuclear Event Scale, the highest level reserved for major accidents such as Chernobyl.

In light of this event, the U.S. Nuclear Regulatory Commission (NRC) began a comprehensive evaluation of its own safety standards to understand what lessons may be learned to better fortify the current fleet of reactors in the U.S. from such an incident. In July 2011, the NRC's Near-Term Task Force released *Recommendations for Enhancing Reactor Safety in the 21st Century*, a list of twelve short and long term actions for the NRC to consider implementing. By March 2012, the NRC issued three orders to the industry calling on them to: improve or replace existing containment ventilation systems on all boiling water reactors, install enhanced instrumentation to monitor water levels in spent fuel pools, and be capable of ensuring reactor and spent fuel pools remain cool in multiple simultaneous events. Subsequent adjustments to safety requirements continue to follow these initial orders, including mandates for improved training of accident mitigation procedures, and a controversial proposed rule to require filters on all containment venting systems to address potential releases (Thompson, 2014).

Although looking to institute new safety measures, the NRC states that it is possible to continue safe operations of reactors while making adjustments, negating the need to shut down any of the current fleet. Even without shut downs though, the economic cost of compliance is hindering an industry that already finds it difficult to compete on a per kilowatt hour basis with other producers like natural gas. Dominion Energy, the operators of six nuclear plants estimates that Fukushima upgrades will cost \$30 to \$40 million per unit, for a total of \$180 to \$240 million for its fleet (Thompson, 2014). Another major industry contender, Duke Energy estimates that it will spend \$350 million over five years to bring its reactors into compliance. This figure does not include an additional \$15 million per unit that it would cost to add the containment venting systems should that rule go through in 2017 (Reuters, 2013). Given these high costs, Duke Energy is electing to retire one of its Florida reactors rather than complete upgrades.

Some of these new regulations may not directly pertain to small and mini reactor designs as they are written for Generation II technology; however, testing for design basis events with multiple simultaneous failures, and more training for on-site accident mitigation could add to the licensing and operational costs of advanced reactors.

4.2.4) Economic Model Working Group

The Generation IV International Forum (GIF) Economic Model Working Group (EMWG) published *Cost Estimating Guidelines for Generation IV Nuclear Energy System* in 2007. The integrated nuclear energy economic model (INEEM) is presented and may provide the best economic framework for Alaska to evaluate total economic costs and benefits. G4-ECONS software is available to implement guidelines and models explained in their publication. INEEM has four parts: construction/production, fuel cycle, energy products, and modularization.

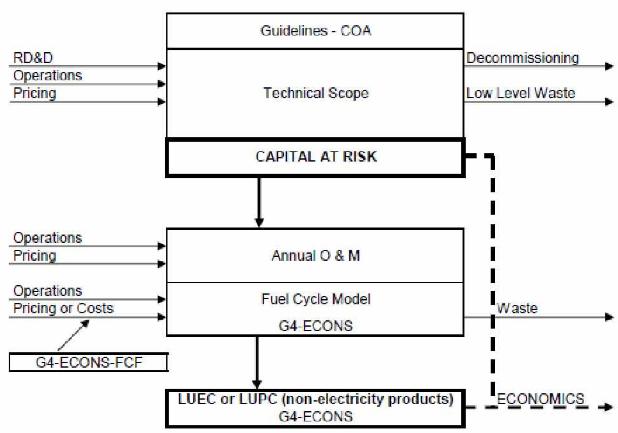


Figure 16: Integrated nuclear energy economic model (EMWG, 2007)

The integrated model incorporates a standard Code of Accounts (COA); a numeric system designed to provide cost information for any component of a project which generates a cost estimating methodology. Over the life of a nuclear power plant expenditures may be categorized as R&D, commercial design, construction, commissioning, operations, fueling, and decommissioning. The COA system allocates these cost categories and further divides them into sub-activities to provide insight into the technical and business issues associated with each concept. G4-ECONS can produce estimates at various level of detail based on input; two-digit, three-digit, and four-digit COA. Increasing number of digits indicates cost categories are further divided into sub-activities. At the two-digit level, subsystem category names should be applicable regardless of the reactor system or technology described and input differs in only two categories. The three-digit level requires differentiation of input that is specific to each type of plant. A technology neutral two-digit COA using G4-ECONS software is not likely to provide an estimate for Alaska more sophisticated than the LCOE estimates provided earlier (Abdulla et al. 2013) (Kuznetsov & Lokhov, 2011) (Rosner & Goldberg, 2011). Alaska will be able to construct a more accurate model than earlier estimates with a three-digit COA with sufficient data input.

A collaborative using the EMWG model to anticipate total costs and benefits to the community is being conducted at Idaho National Laboratory. The Energy Policy Institute - Center for Advanced Energy Studies (a public/private partnership between Idaho National Laboratory, Boise State University, Idaho State University, and private industry) is developing a model to evaluate *Economic and Employment impacts of Small Modular Nuclear Reactors* (Solan et al. 2010) (Black, 2012). Researchers estimate overnight costs and LCOE based on a 3-digit COA from the EMWG. Using these estimates, the Energy Policy Institute (EPI) is modelling economic impacts to include economic incentives for the community.

1. Sales (output) economic impacts represent changes in total transactions
    a. Broadest measure of economic activity
2. Value-added impacts are a measure of GDP, at the national/regional/or local areas. Includes employee compensation and proprietor income, other property income, and indirect business taxes
    a. Most accurate broad measure of economic impacts
3. Employee compensations and proprietor income measure earnings and payroll impacts
    a. Easiest to understand
4. Employment (jobs) includes the impacts on full and part-time workers
5. Indirect business measures the impacts on sales taxes, property taxes, excise taxes, and all other taxes except personal income taxes and corporate income taxes.
    a. Tax impacts of a change in a final demand, excluding income taxes

This approach utilizes total costs from bottom up capital estimates. Licensing and design costs are included, and first-of-a-kind costs may be individually estimated to represent a more appropriate market share. EMWG model software is available to the public but accurate results derive from accurate input and specific input criteria, especially technological design, remain proprietary at this time. The input data for the EPI model have not been published, only the model outline. The University of Alaska would likely be capable of facilitating technology specific data for the objective of generating EMWG three-digit COA through cooperation with Idaho National Laboratory and Center for Advanced Energy Studies.

4.2.5) Operator License Fee

According to the Omnibus Budget Reconciliation Act of 1990, the NRC is required to collect 90 percent of its annual appropriated budget through two types of fees: one that recovers the costs of providing services such as licensing and inspection activities to applicants, and an annual fee paid by all licensees, which recovers generic regulatory expenses and other costs not recovered through fees for specific services (Nuclear Energy Institute, 2010). The NRC must therefore be careful in its program selection as the majority of these costs will be shouldered by industry, impacting the bottom line at which they are able to operate. This can be illustrated by observing the annual operating fee for 2014, which increased 21% from the 2013 rate of $4.4 million to $5.3 million. The reasons given by the NRC for this rate change are a seven percent increase in the agency's operating budget, and the closure of two reactors, leaving fewer reactors to divide the budget between (Goldberg, 2014). This fee raise could exacerbate economic constraints of other reactors forcing even more closures, and fewer plants to divide the fee amongst.

Annual fee regulations, codified in 10 CFR 171 require that each operating nuclear power reactor pay the same annual fee, regardless of its size. This approach is a significant economic disincentive to the development of small and medium reactors, particularly multi-module plants that would be charged per reactor (Nuclear Energy Institute, 2010). Although it is possible to seek an exemption to this fee, there are no guarantees that one will be given, complicating economic analysis. In 2010, the NRC proposed a possible rule change that would base annual fees on a sliding scale relative to the power that is produced; however, at this time, the NRC is withholding a decision on this rule change until the review of a DC or COL where this may be applicable.

In examining a sliding scale, prior studies of the NRC in 1986 and 1995 found that there is not a relationship or predictive trend between regulatory resources and thermal power rating (Nuclear Energy Institute, 2010). Moreover, the existing fleet of large LWRs is vocally opposed to the rule change if it means they will bear the burden of paying for the regulatory framework development costs associated with new technologies. The Nuclear Energy Institute (NEI), the nuclear industry lobby organization, has proposed a compromise version of the sliding scale fees for small, medium, and large reactors that would carry minimum and maximum fee amounts to address some of these inequity concerns. Depending on whether these minimum and maximum fees are set to be constant over time, this structure could require an amendment to be made to the 1990 Omnibus Budget Reconciliation Act.

The minimum fees proposed by the NEI are in line with guidelines already issued by the NRC covering research/test reactors and spent fuel storage facilities, which are $81,700 and $148,000 respectively. The NEI proposes setting the minimum for reactors above 250MWt at $115,000. It is unclear at this time if reactors with a smaller thermal output would be exempt altogether. As a side, nonprofit educational institutions are generally exempt from fees for research and test reactors under 10 CFR 170.11 (NRC, April, 2013).

4.2.6) Insurance Requirements

In order to protect the public from the liability of nuclear incidents, Section 170(b)(1) of the Atomic Energy Act requires that licensees for reactors above 100 MWe carry the maximum amount of insurance available from private sources and also participate in a secondary retrospective insurance plan (Johnson, 2011). Presently the maximum amount of insurance available through private insurance is $375 million, which is supplemented by a capped payment of $17.5 million per year to the secondary insurance plan. As of 2011, the secondary insurance pool stood at approximately $12 billion dollars.

For those reactors generating less than 100 MWe, or that do not generate electricity and produce more than 10 MWt, liability insurance rates are set between $4.5 and $74 million using a formula that calculates thermal power against the site's population. Moreover, these sized reactors are excused from participation in the secondary insurance plan. This system may lead to inequity for currently proposed iPWR designs or a lack of proper coverage for these multi-modular units. Under the present calculation, a modular reactor design that has individual power reactors producing less than 100MWe each can use the less costly system, even if the total power produced by the site is an excess of 100 MWe. This incentivizes modular units with smaller individual reactor outputs against those that produce greater than the 100MWe threshold. This inequity is further complicated by the potential for a nuclear site to be capable of producing several hundred MW of electricity but carrying a minimum amount of insurance that may not be able to sufficiently protect the public in the event of a nuclear incident.

In a position paper released by the NRC's Office of New Reactors, they stated that current regulations could be reinterpreted to protect against this potential inefficiency. Under 10 CFR 140.12, the NRC has broad discretionary authority to define the word "reactor". Thus, the NRC can issue a guidance document, which provides a new definition for the term reactor that encompasses the total combined power production at a plant site. Again, the NRC is holding off on this guidance until the receipt of a COL or DC application that this rulemaking would pertain to.

Summary

The initial economic models provided a range for LCOE of expected advanced reactors with potential for the Alaskan market. This allows a general baseline to examine projected technology costs as compared to current electric costs in the state. Most of the initial estimates provided (Rosner & Goldberg, 2011) (Abdulla et al. 2013) indicate advanced nuclear reactors may be competitive in the state. However, it was noted that general estimates often incorporate multiple unit purchases so Alaska would likely pay more than vendor estimates. Total economic burden should incorporate secondary fees for licensing, insurance and operations, but many opportunistic models do not project such expenses into their LCOE. There are also potential cost benefits to the operator such as tax credits and the local economy may anticipate increased employment, sales and property tax income.

One model capable of incorporating these variables to produce state specific economic data is the EMWG three-digit COA. Cost estimates from this model may prove the most accurate for local economic costs and benefits and aid as a bellwether against a vendor's proposal in the future. However, the input for such a model requires detailed and accurate data among the four categories. Technology specific data should be obtained from vendors, and uncertainty errors regarding additional fees minimized. Output enables state leaders to compare total costs to economic drivers in the community for an accurate representation of fixed cost to the consumer over a period of time equivalent to the life of vessel.

4.3 Public and Environment

Fundamental to the development of any energy project is a thorough understanding of the impacts it will have on the socio-ecological environment. Given global nuclear history, these considerations are magnified for projects proposing its utilization. The United States passed the National Environmental Policy Act in 1970 to create an organized decision making process for reflections of socio-ecological impacts and involvement of the public through the use of EIS documents. This section will not attempt to detail the breadth of environmental studies that will be required to properly analyze impacts, but will instead focus on two aspects that may be unique to the use of nuclear; storage and disposal of used nuclear fuel, and public perception.

4.3.1 Storage and Disposal of Used Nuclear Fuel

Perhaps the least mentioned factor regarding advanced nuclear power in Alaska is temporary storage of used nuclear fuel and eventual transportation for permanent disposal. Gen III+ iPWRs promote a vessel life of 60 years. The fuel cycle for the mPower is designed at 4 years while the NuScale is 2 years. Upon refueling the vessel, encapsulated spent nuclear fuel would be removed. This would occur (15-30) times over the life of the power plant. These power plants may require on-site storage of used nuclear fuel for at least 60 years.

Gen IV mini reactors that have been evaluated here are factory sealed designs without the option to refuel. This vessel operates for the life of the fuel cycle and vessel acts as containment cask awaiting transport to factory reconditioning or final repository. No additional storage infrastructure is anticipated in this scenario; however the unit would need to remain on site post-shutdown until safe for transport, potentially 6-12 months depending on the design. Used nuclear fuel is a design consideration of vessel structure which would be approved by NRC design certification.

In either case, 40 CFR Part 197 provides an example of three standards for consideration when storing used nuclear fuel: individual protection, human intrusion, and groundwater (Hansen et al. 2014). The individual-protection standard sets an overall dose limit of 100 mrem per year for members of the general public (which is about a third of the average American's annual dose from nature) and 5,000 mrem per year for workers (NRC, 2013). The overall annual dose limit takes into account exposure through all pathways. The human-intrusion standard accounts for releases from a waste container from human error and into the underlying ground water. Ground-water protection standards provide the same dose and concentration limits as EPA's drinking water standards (Hansen et al. 2014).

The US does not currently accept spent fuel from commercial vendors; no such site exists. The Atomic Energy Act (AEA) of 1954 stipulated that disposal of commercial spent nuclear fuel would be the responsibility of the federal government. By 1956, the National Academy of Sciences (NAS) recommended deep geologic disposal as the most promising method for disposing of commercial nuclear waste (Sanders, 2013). In 1982 congress passed the Nuclear Waste Policy Act (NWPA), which stipulated three essential items: 1) federal agencies should accept commercial fuel waste for permanent disposal by 1998, 2) required identification of permanent disposal sites (repositories), and 3) a nuclear waste fund was establish with fees collected from electricity generated from nuclear power. In 1986, the Energy Department recommended three repository sites for potential licensing, located in Nevada, Texas and Washington. The US congress amended NWPA in 1987 to designate one national repository in Yucca Mountain, NV, and terminate any further considerations for multiple repository sites. The next decade yielded exploratory studies at Yucca Mountain and initial public hearings were established, but the DOE was not able to begin receiving commercial waste in 1998 as stipulated by NWPA. A decade later, the DOE submitted a Yucca Mountain license application to the NRC in 2008.

Executive action to cease this licensing process was encouraged by then Senate Majority Leader Harry Reid-NV, and many of his constituents who were wholly opposed to the development of Yucca Mountain as a national repository. In 2009, the executive branch declared an end to the Yucca Mountain process and the DOE petitioned to withdraw its license application from NRC. The NRC Atomic Safety and Licensing Board denied the motion to withdraw its license application and said the DOE lacked authority to withdraw the application under the law. In July, 2011, the U.S. Court of Appeals for the D.C. Circuit rejected the DOE from unilaterally terminating the Yucca Mountain development process. In response, the executive branch ordered NRC to close out all pending issues by the end of the fiscal year, September 30, 2011. As a result, the Yucca Mountain license was suspended.

A 2013 federal appeals court ruled that the executive was “flouting the law” when it ceased its review on Yucca Mountain (Ward, 2013). The District of Columbia Circuit Court of Appeals posted a 2 to 1 decision stating that “Congress speaks through the laws that it enacts.” The NWPA of 1983 calls for the NRC to consider an application to store nuclear waste and issue a decision within three years. The license was submitted in 2008 and the NRC’s deadline, as stipulated by Congress, had passed.

In summation, purchasing a Gen III+ or Gen IV nuclear power plant does not inherently guarantee the removal of spent nuclear fuel from the site. A Gen III+ iPWR may require infrastructure to store nuclear waste for up to 60 years. Both Gen III+ and Gen IV require waste transportation to a permanent disposal site out of state. It has been established that the federal government does not currently accept waste fuel from commercial nuclear power plants. Current DOE management strategy stipulates the implementation of a pilot interim storage facility by 2021, followed by a larger interim storage facility by 2025. These dates bode well for state decision makers. If the federal government realizes its responsibility to receive used fuel from nuclear vendors by 2025, a case may be made for permanent disposal outside Alaska. However, if the federal government is not receiving commercial waste, any claim to removing used fuel from the state would need substantiation from a specific vendor contract; where the vendor owns the waste and guarantees removal at end of vessel life.

Once the Yucca Mountain license was suspended, the executive established a Blue Ribbon Commission (BRC) in 2011 to review America's Nuclear Future. They recommended a review for new repository sites, authorization of federal interim storage, and a new federal agency responsible for commercial nuclear waste management (NPJ, 2013). In addition, BRC recommendations stipulate a consent based approach when considering new interim storage facilities and permanent repositories.

In response, a bill was introduced in the Senate; Nuclear Waste Administration Act (NWAA). NWAA was not presented for a vote but remains in committee. If passed, NWAA will create a new federal corporation (U.S. Nuclear Fuel Management Corporation), and a potentially two centrally located above ground interim storage facilities (Socacool and Funk, 2013). NWAA contains legislative language requiring DOE to use a consent based process to solicit proposals from communities interested in hosting above ground interim storage sites. As the BRC established, this consent based approach requires the consent of state and local governments, public hearings and ultimately, congressional approval (Koss and Gardner, 2012).

4.3.2 Public

Consent based methodologies and frameworks have been outlined by the DOE's 2013 report *Strategy for the Management and Disposal of Used Nuclear Fuel and High-Level Radioactive Waste*, which represents a larger collaboration among, DOE, University of Oklahoma, and Sandia National Laboratories (Jenkins-Smith et al. 2012) (Jenkins-Smith et al. 2013) (DOE, 2013). These studies have outlined a design process and identified public preferences associated with consent based siting for intermittent waste facilities. This process encourages communities to volunteer to host a storage facility in return for the expectation of economic activity associated with the project. The anticipated economic activity associated with the project was discussed earlier and may be modelled with EMWG three-digit COA method (EMWG, 2007) (Solan et al. 2010) (Black, 2012). Figure 17 illustrates a consent based process envisioned for intermittent storage facilities.

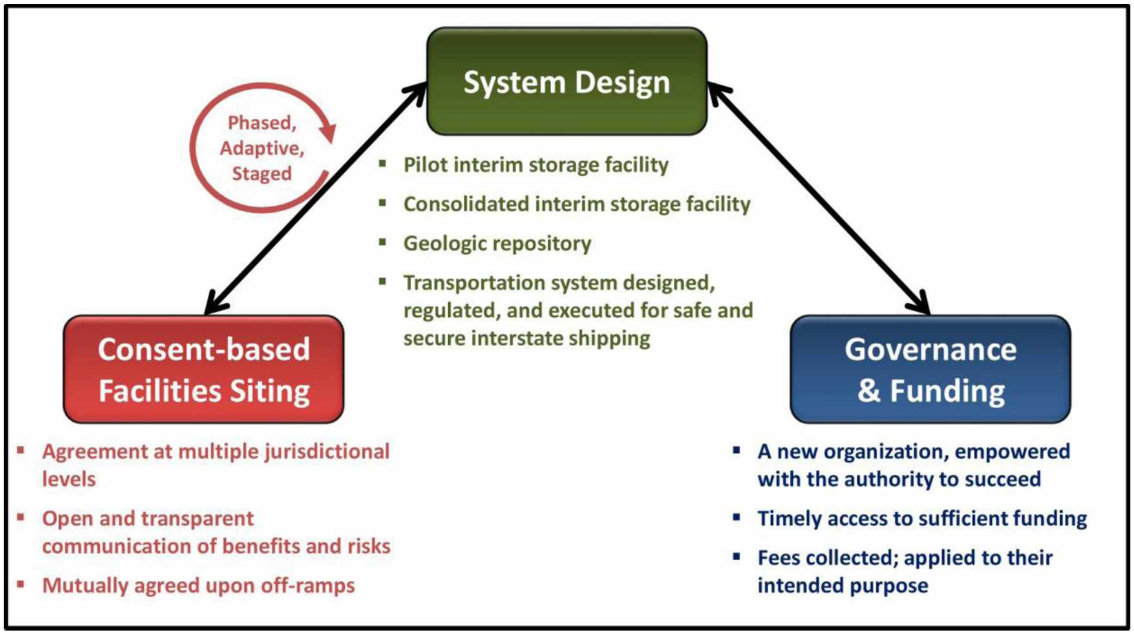


Figure 17: DOE consent-based strategy as proposed through BRC and senate bill NWAA (DOE, 2013)

The public is a stakeholder in any potential scenario where advanced reactors are deployed in Alaska, and a consent based process similar to the illustrated strategy is required. Gaging public support for nuclear energy is an increasingly active pursuit of many policy analysts because the federal government has repeatedly stated that energy independence by 2020 and increasing nuclear representation in its domestic energy portfolio are national goals. Recently, researchers developed a representative model for gaging public's nuclear opinion by distinguishing causal factors into seven attitudinal indicators (Stoutenborough et al. 2013). The study utilized a national public opinion poll that focused on energy issues and found a significant portion of the populous at "unsure" or neutral towards nuclear policy. They concluded that people more knowledgeable about energy issues are more supportive of nuclear policy.

National public support for nuclear energy appears neutral to favorable. Westinghouse has four new reactors approved for construction in Georgia and South Carolina. A third, half-finished, reactor resumed construction in Tennessee. NuScale and Fluor are in a pre-construction phase in Idaho. All of these projects are cooperatives with regional utilities and associated with favorable state legislators. The Georgia legislature authorized an increase to energy bills for those consumers who will use power from the new nuclear construction, allowing the utility to collect monies up front to minimize risk on capital investments. This is a good example of the state providing fiscal incentives to vendors, similar to federal incentives in Energy Policy Act. In this case, the public provided consent to the development of power plants and to cost-sharing in the project.

When compared to these current examples, Alaska's nuclear energy past has a critical flaw; failure to incorporate the public as a stakeholder. The Gen I reactor that was deployed at Ft Greeley was a project with the Army Nuclear Power Program. A cooling pipe froze in the winter resulting in a discharge of activated water into the environment (Harris, 2010). The public was not properly engaged to quantify the event, identify potential risks, or to demonstrate actions underway to mitigate the situation. The reactor has since been removed and the site is in stage three of a four stage decommissioning process overseen by the Army Corps of Engineers. The radio-isotope thermal generators operating the seismic monitoring site at Burnt Mountain exhibited normal operation, but failure to recognize the public as stakeholder resulted in a terminated project for an otherwise successful application.

A fundamental pretext to potentially achieve public consent for advanced nuclear power is knowledge. The public should be informed of the engineering design being discussed; timeframes for regulatory process, risks associated with operations, economic commitments and incentives, and waste management plans. Early in this process, the public must be provided a proper frame of reference to distinguish a small reactor from the current large reactors. The likelihood of incorporating small or mini reactors into the state's energy sector requires a multiple stakeholder cooperative where the public is a consenting member. Recognizing the public as a stakeholder is an important precursor to defining specific clients in Alaska which may benefit from small or mini reactors, and one of the incremental steps required for this technology to be realized in the state.

Chapter 5 Next steps

Reactor technology, market competitiveness, human health and environmental protection have been offered as factors affecting the likelihood of advanced nuclear technology in Alaska. A hypothetical roadmap is now developed to consider how the above factors may align in order to bridge the gap from R&D to the marketplace. There are three potential clients for small and mini nuclear power plants in Alaska. The public was recently introduced as a necessary participant in the earliest stages of development. Together, the public, state and university stakeholders form the civilian client. Two other potential clients are military and remote industry as seen in the table below.

Client	**Civilian**	**Military**	**Remote Industry**
Stakeholders	State	Army	Mining
	University	Air force	Oil and Gas
	Public	Coastal Ports	Shore Power

The military client has three potential stakeholders. The army and air force will be discussed as one stakeholder and referred to as Alaska Command (ALCOM). The coastal port stakeholder will be addressed independently.

The projected scenarios will illustrate client cooperatives required to initiate an early site permit and further courses of action needed to develop a Gen III+ iPWR in 15 years. Generally, a large utility would partner with one specific client to develop first-of-a-kind technology. The large utility would provide significant up-front capital and absorb fiscal risks if the client becomes a contractual customer. Examples of this large utility-client partnership for potential lower 48 small reactor deployments are shown in figure 18.

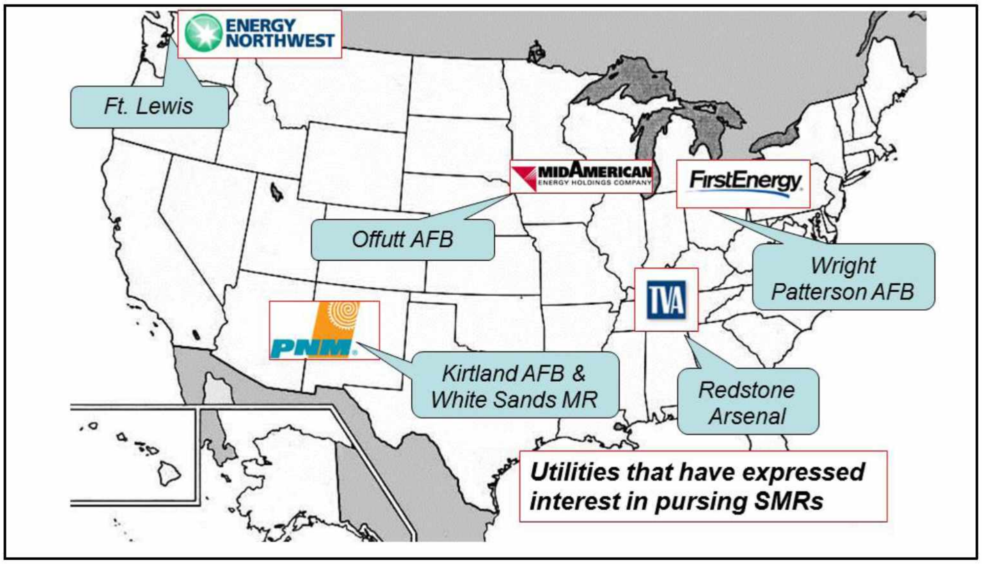


Figure 18: Potential Military pairings with Utilities in the lower 48 (Welling, 2010)

A utility in Alaska is comparatively small to these lower 48 examples and likely would not be able to provide the upfront capital required for such a project. Therefore, the potential for advanced reactor deployment in the state requires a cooperative of more than one client to incorporate a greater number of stakeholders. The alliance of two clients in Alaska may provide a driving factor capable of realizing this technology with potential to reduce the burden upon local utilities for upfront capital.

Remote industry, from a pragmatic view, may secure large benefits from a nuclear power plant, especially mining. Process heat applications have been reviewed and the potential for mining operations to utilize both power and thermal energy for production may prove significant. However, the industrial client is not considered a likely early-stage cooperative participant. Perhaps, with nth-of-a-kind production, and data precedent, this technology may be located in far remote areas, to include villages and coastal ports as well. Collectively industrial, remote, or coastal applications are assumed as second-stage clients because it is more practical that first deployment in the state would require a location along the railbelt. This would allow the new power source to integrate into the current gird portfolio, and not serve as a sole-source unit. With those constraints, the potential to realize this technology requires a military-civilian alliance; six potential stakeholders.

5.1 Dual-Client Cooperative

Two assumptions have been made, a first module will be located along the railbelt and this will require a military-civilian cooperative. Fairbanks North Star Borough meets these criteria and will serve as the location for a hypothetical siting analysis. The region contains all required stakeholders for the appropriate alliance: Public, ALCOM, University and State. Fairbanks has two military bases with significant electrical and thermal requirements. Combined, the cities of North Pole and Fairbanks constitute the second highest energy demand in Alaska. If these clients collectively sought an advanced nuclear reactor, they would initiate a driving force for the siting process. The initial ALCOM-State cooperative would immediately need to offer a potential site for evaluation. For this discussion, the site will be Eielson Air Force Base, and the distribution of thermal/electric energy will be allocated among the stakeholders. Public forums are required to sustain any initial momentum, and it is important to communicate that site considerations do not equate to purchasing a product.

A dual-client cooperative would need to acquire federal partners at the earliest stages. ALCOM offers direct communication to Department of Defense (DoD) leaders. In fact, DoD has ordered all their bases to conduct energy studies and ALCOM has been directed to guarantee base-load power to maintain Arctic superiority (10 USC 138c) (ODUSD-I&E, 2013). Additional DoD partners ALCOM may require include NORTHCOM, PACOM, STRATCOM/SMDC, service installation management proponents, DARPA, and NRO (Northern Command, Pacific Command, Strategic Command/Space and Missile Defense Command, Defense Advanced Research Projects Agency, and National Reconnaissance Office). The state client should exercise its federal representation at the US Senate, and engage Senator Murkowski. All of these secondary and tertiary client associations are required early in the process to sustain initial momentum of the dual-client cooperative.

5.2 Early Site Permitting

Early Site Permitting (ESP) serves as a conduit where the dual-client cooperative may incorporate an innovative licensing pathway to resolve site safety, environmental protection, and emergency preparedness issues while the reactor technology matures over the next decade. As mentioned, this process may be initiated independent of a specific nuclear plant, can be valid for 10 – 20 years and renewed for an additional 10-20 years. The cooperative is granted the ability to resolve siting issues with ample time to find a reactor design suitable to their location. ESPs are pre-application reviews occurring before the COL process, and does not commit to any purchase of a nuclear power plant.

General requirements for Environmental Reviews (ER) are set out at 10 CFR 51.45. Additional ER requirements are in 10 CFR 51.50 - 51.68. The review of an ESP application focuses on the environmental effects of construction and operation of a reactor and the reviews need not include an assessment of benefits (for example, need for power). The ESP application will identify physical characteristics unique to the proposed site that could pose a significant impediment to the development of emergency plans. A preliminary analysis of evacuation times would be conducted where impediments to the development of emergency plans may be identified. Moreover, effects on community land use, such as recreation and subsistence, are also addressed. In total, the ESP application must address all of the following

- Boundaries of the site to include exclusion areas
- Characteristics of the site; seismic, meteorological, hydrologic, and geologic data
- Location and description of all nearby industrial, military, or transportation routes
- Existing and expected future population of the area
- Evaluation of alternative sites to determine if there is an obviously superior alternative
- General location of power plant at the site
- Maximum radiological and thermal effluents expected
- Type of cooling system anticipated
- Hypothetical accidents and radiological dose consequences
- Emergency planning

A completed EIS is required during this process. Typically, a public meeting is held 6-12 months before and application is submitted for an ESP to familiarize the public with safety and environmental aspects, location selection, and regulatory process. Availability for the public to interact during the process will be communicated at these meetings before the process ensues and may be seen in figure 19.

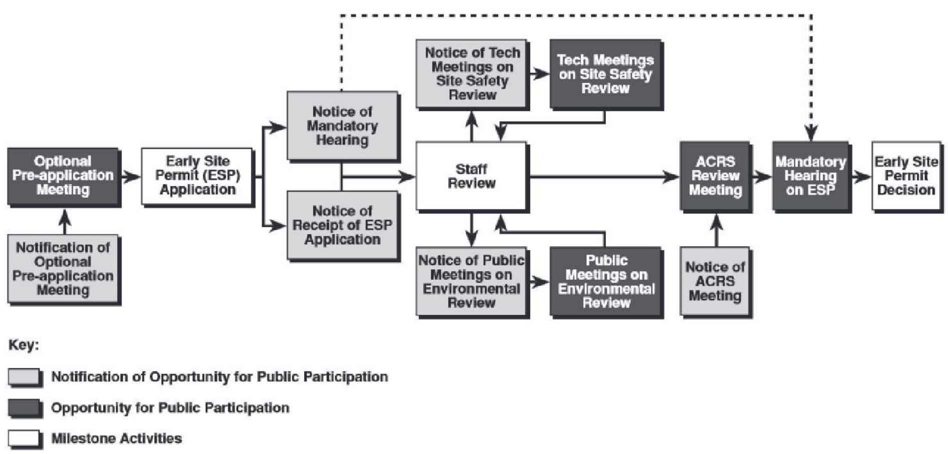


Figure 19: Opportunities for Public Involvement during Early Site Permits

Source: http://www.nrc.gov/reading-rm/doc-collections/nuregs/brochures/br0298/br0298r2.pdf

As environmental evaluations ensue, up-front capital will be required. Earlier, the dual-client cooperative was introduced and federal partners were offered for each client. It is feasible, under precedent set from Energy Policy Act and the DoD initiative to ensure energy resilience, to obtain federal monies which offset the permitting process. Once the ESP process is complete and a specific reactor design selected, a modified COL process may begin as presented earlier. Collectively, if the factors affecting total cost of this project prove favorable, a Gen III+ iPWR could contribute to the interior Alaska railbelt at Eielson Air Base under a Military-State dual cooperative by 2030. If successful, a small nuclear power plant will establish state precedent for reliable base-load power with thermal applications. At this point, there is potential for second-stage clients to appreciate benefits of a state-proven technology utilizing nth-of-a-kind reactor modules.

5.3 N-th-of-a-kind and Second Stage Clients

5.3.1 Yukon Corridor

Second stage implementation may occur following a FNSB test case, and could further penetrate nuclear into the state's energy portfolio. Industrial applications have been mentioned regarding second stage clients, but the rural village will first be evaluated. Connecting the villages of the Yukon corridor is a method to implement a future integrated grid while encouraging economic development among villages. Tribal corporations may form a cooperative with the state where a single iPWR would be capable of transmitting electricity to multiple interior villages. Connecting villages to reliable base-load power is a long term goal of many. The All Alaska Energy Project is one such example that proposes high-voltage direct current long distance transmission to villages from a natural gas power plant source located on the North Slope (allalaskaenergyproject.com). Perhaps, an iPWR could achieve similar goals, but reduce transmission lines by hundreds of miles by locating the power source closer to the client. In effect, connecting remote communities to base-load power could reduce dependence upon imported fuel and associated supply chain interruptions while providing an extended flat rate assurance for energy over a period of years.

A possible future integrated grid allows for multiple alternative power sources and co-generation. Small and mini reactors may become a critical component of integrated grid systems to ensure ample base load for consumers while other alternatives (wind/solar) contribute intermittently. Connecting the villages of the Yukon corridor is one concept envisioning an integrated grid while encouraging economic development among villages. In addition, many Native Corporations have existing alliances among industry partners. A Native Corporation-Industrial client cooperative may be the most powerful alliance presented in these scenarios. A proper structuring of this alliance may benefit many villages and potentially promote jobs and economic development in remote areas. Natural resources could be mined in areas currently inaccessible while minimizing the structural footprint, eliminating carbon emissions, and reducing dependence upon imported fuel as compared to existing industrial applications. A new energy policy capable of delivering base load power to the Yukon Corridor has the potential to build economies through manufacturing and development to a region currently excluded due to lack of energy.

5.3.2 Coastal Ports and Shore Power

The Alaska Deep-Draft Arctic Ports Navigation Feasibility Study is a 2014 public report conducted by the US Army Corps of Engineers. The purpose of the study was to identify potential deep-draft arctic ports, and was conducted based on three key points: 1)National security 2)Large vessel traffic is increasing and more than 60% of these vessels are foreign flagged 3) Greater traffic heightens risk of incidents, accidents, and increases national security considerations (USACE, 2014). From 2012 to 2013 arctic sea traffic increased by 54% and further increases are expected if arctic sea-lanes continue to open. Areas discussed in this study included Nome, Port Clearance, Point Spencer, and Cape Riley, which are potential west coast deep-water port options. If arctic sea traffic continues to increase, it is reasonable to expect that DoD will develop a deep-water port to allocate resources. A floating nuclear power plant similar to the Russian KLT-40S could prove sufficient to meet power demands during development and operations with potential to distribute heat or desalinate water.

The clients in this scenario may be military-state or only military depending on the intended applications of the port. Since the late 1940s, nuclear power has been used by the U.S. military for power production and propulsion. Most significantly, the U.S. Navy has accumulated over 6200 reactor-years of accident-free experience involving 526 nuclear reactors (World Nuclear Association, 2014). Presently, the Navy operates 103 reactors that are used in the U.S. fleet of submarines and supercarriers. The reactors used on these vessels are iPWR designs that utilize highly enriched uranium (uranium enriched beyond 20%). Accordingly, the Naval Nuclear Reactor Program is overseen by DOE's National Nuclear Security Administration. Due to the sensitivity of naval operations, and the use of these reactors in marine settings instead of stationary, the DOE handles the licensing of these reactors independent of the NRC.

Another military branch with experience operating nuclear reactors is the Department of the Army. From 1954-1977, the U.S. Army maintained the Army Nuclear Power Program (ANPP). While the Navy's focus is on the use of nuclear for propulsion, the Army studied the potential uses for power production; specifically, the possible applications for remote sites and forward deployment. Through the Army Reactor Office, the U.S. Army Corps of Engineers received the permits to construct and build nuclear facilities. All totaled, the U.S. Army operated eight reactors during the twenty year program, including Fort Greely in Alaska, a barge mounted power plant, and other remote installations such as Greenland and Antarctica. Concerns over the cost of the program, and a focus on other issues such as the Vietnam War led to the canceling of the ANPP. Presently the U.S. Army Corps of Engineers continues to hold permits to three of these facilities as it still needs to complete decommissioning activities (Federation of American Scientists, 2001).

Again, in this scenario, an nth-of-a-kind reactor with precedent may provide energy needed to develop these ports without the introduction of diesel power plants, fuel tank farms, and associated infrastructure. The small size of a reactor with proven ability to remove decay heat in a transient event, may offer an alternative to the existing and complex cost-supply chain matrix. The supply chain will be even more vulnerable for arctic sea ports. The early sea ice during the winter of 2011-12 in the Bearing Sea demonstrated how Nome was isolated before their seasonal fuel delivery. This scenario is unacceptable for a military operation so a dependable base-load energy source available for a number of years may prove more prudent to achieve a long range vision of energy resilience.

Chapter 6 Conclusion

Advanced small and mini nuclear technologies are likely to incrementally become available beginning in 2025. As the coal and diesel generators of interior Alaska reach end of life and new purchase discussions ensue, advanced nuclear technologies may be possible solutions that state leaders will consider. If the product competes in the market, policy becomes defined, and waste plans in order, Alaska may experience this technology by 2030. Likely, this process would be facilitated by a Military-Civilian client cooperative within the interior railbelt. In review of the ESP timeline, a cooperative would need to gain traction in the next few years to initiate momentum as a precursor to acquiring federal partners. The public is a necessary stakeholder from the earliest stages of permitting, and the University system may provide the best conduit to continue research in advanced reactors while communicating with the public about the technology and permitting process during outreach education opportunities.

Second stage clients may begin to develop nuclear-integrated plans advantageous to their specific needs as operational data and n-th-of-a-kind production ensues. Tribal corporations could develop a Yukon Grid Corridor or partner with remote industry in economic development. This power source may assist the military's vision of establishing an Arctic deep-water port while contributing to their goal for energy resilience. The vision of small nuclear technology will clarify as more Gen III + and Gen IV technologies are developed worldwide. Understanding, identifying, and quantifying all factors contributing toward the total cost of this emergent technology may be continued through the University of Alaska. Promoting research in advanced nuclear development and planning is a state responsibility, and in the constituents best interest that accurate, current, and levied facts are available through public forum.

Perhaps the most applicable case study to evaluate the technological development and regulatory process for a Gen III+ iPWR will be the Flour-NuScale project in Idaho Falls, ID. The UA system in cooperation with ACEP should further research cooperatives with INL and CAES. A research cooperative between UAF-ACEP and CAES to study advanced reactor technology for Alaska was initiated in 2014 at the Center for Space Nuclear Research (CSNR) in Idaho Falls. At CSNR, engineers and student fellows have been working to advance 1 MWe reactors for use by NASA in space exploration programs. Thus far, their research has indicated that some aspects of the space reactor technology may be applicable to northern deployment as there are many similar operational requirements such as: 1) desire for semi-autonomous operation and smart controls, 2) safety, reliability, and long life, and 3) retention of fission products in the event of an accident. Moreover for CSNR, pursuing a complementary investigation of terrestrial applications could facilitate technology maturation thereby mitigating risk for space exploration, and enhancing affordability via an expanded market base. In 2014 three UAF students were selected as fellow to CSNR where they worked on a team to design a Gen IV mobile reactor for northern deployment. Further research cooperatives between UA and INL may provide detailed analysis to any of the contributing factors presented here and would serve to keep state leaders current and accurate on matters of technology, policy and economics, while evaluating potential sites domestically. The modified EMWG three-digit COA model that is currently being developed at CAES may be adopted for Alaska modelling and should be studied as their findings become public.

The steps to initiate deployment are as follows:

- Dual-client cooperatives, public involvement, and continuation of research partnerships with INL-CAES. As international development of these advanced designs are progressing steadily, and as the technology matures, the state will be faced with long-term energy decisions to include small reactors.
- Total costs of these various technologies must be assessed independently to verify their claims. This report was provided in an effort to offer state leaders updated technological evaluations, an economic model to consider for accurate representation of fixed cost to the consumer, and an ESP which illustrates how a project may move forward under a dual-client cooperative. Total costs must include secondary and tertiary factors often not included in opportunistic reviews of some designs. Together, these incremental steps will assist state leaders as the application of nuclear energy is considered for Alaska.
- Gen III+ will be available before Gen IV reactors. Initial Gen III+ deployments are likely to promote energy diversification in the interior. The military may take a leading role in providing thermal energy for domestic district heating. Strategic commands at Ft. Greeley and Clear Air Base may seek nuclear power for energy independence. The reactor license at Ft. Greeley still exists because decommissioning is not complete. This may facilitate an avenue for a military strategic command to reestablish nuclear power in Alaska
- Second-stage implementation may entail more remote applications among industrial stakeholder, especially in remote mining operations. Additionally, nuclear power will remain an option for the development of an Arctic deep water port.

References

Abdulla, A., Azevedo, I. L., & Morgan, M. (2013). Expert assessments of the cost of light water small modular reactors. *Proceedings of the National Academy of Sciences of the United States of America, 110*, 9686-9691.

Alaska Center for Energy and Power. (2011). *Small-Scale Modular Nuclear Power: An Option for Alaska.* Fairbanks: University of Alaska.

American Nuclear Society (July, 2010) *Interim Report of the American Nuclear Society President's Special Committee on Small and Medium Sized Reactor (SMR) Generic Licensing Issues*. La Grange Park, Illinois. Accessed at: http://www2.ans.org/pi/smr/ans-smr-report.pdf

Arie, K. (2009). Applicability of Small Fast Reactor "4S" for Oil Sands Recovery. *30th Annual CNS Conference / Western Focus Seminar.* Calgary, AB, Canada: Toshia Corporation.

Babcock & Wilcox. (2014, April 14). B&W Announces Restructuring of Small Modular Reactor Program. *babcock.com*.

Bradford, P. (July 11, 2013). *Nuclear Renaissance Was Just a Fairy Tale.* The Guardian. Accessed at: http://www.theguardian.com/environment/2013/jul/11/nuclear-renaissance-power-myth-us

Christian, C. (2007). *Building Drinking Water Capacity in Native Alaskan Villages*. Retrieved from National Environmental Public Health Leadership Institute.

COGEN Europe (September 2014). *Industrial Renaissance in Europe*. Accessed at: http://www.cogeneurope.eu/medialibrary/2014/09/17/d58f6e60/17092014%20COGEN%20Europe%20Position%20Paper%20Industrial%20Renaissance%20In%20Europe.pdf

Department of Energy. (August, 2008). *Next Generation Nuclear Plant Licensing Strategy: A Report to Congress*. Accessed at: http://pbadupws.nrc.gov/docs/ML0822/ML082290017.pdf

Department of Energy. (April, 2010). *Next Generation Nuclear Plant: A Report to Congress*. Office of Nuclear Energy. Accessed at: http://www.energy.gov/ne/downloads/next-generation-nuclear-plant-report-congress

Department of Energy. (December, 2013). *Energy Department Announces New Investment in Innovative Small Modular Reactor*. Accessed at: http://www.energy.gov/articles/energy-department-announces-new-investment-innovative-small-modular-reactor

European Commission. (2014). European Biofuels Technology Platform. Accessed at: www.**biofuels**tp.**eu**

Faibish, R. S. (2014). Small Modular Reactors: The Promise of Clean, Reliable and Secure Source of Energy. *NEI Small Reactor Forum.* US Senate Committee on Energy and Natural Resources.

Fay, J. A., & Golomb, D. S. (2012). *Energy and the Environment.* New York: Oxford University Press.

Federation of American Scientists. (January, 2001). *Highly Enriched Uranium: Striking a Balance Appendix D Military Reactors*. U.S. Department of Energy. Accessed at: http://fas.org/sgp/othergov/doe/heu/appd.pdf

Fehrenbacher, K. (February 19, 2010). *Nuclear Power by the Numbers*. Gigacom. Accessed at: http://gigaom.com/2010/02/19/nuclear-power-by-the-numbers/

Forsberg, C. (2013). Hybrid systems to address seasonal mismatches between electricity production and demand in nuclear renewable electrical grids. *Energy Policy*, 333-341.

Goldberg, K. (April 14, 2014). *Nuke Plant Operators Will Pay More Under Revised NRC Fees*. Law 360. Portfolio Media Inc. Accessed at: http://www.law360.com/articles/528001/nuke-plant-operators-will-pay-more-under-revised-nrc-fees

Halfinger, J. A. (2012). The B&W mPower Scalable, Practical Nuclear Reactor Design. *Nuclear Technology*, 164-169.

Heffron, R. J. (2013). Nuclear Energy Policy in the United States 1990-2010: A Federal or State Responsibility? *Energy Policy, 62*, 254-266.

Holl, J. M., Anders, R. M., Buck, A. L., & Dean, P. D. (1985). *United States Civilian Nuclear Power Policy, 1954-1984: A History.* Washington, DC: Department of Energy.

Idaho National Laboratory. (July, 2011). *NGNP Nuclear-Industrial Facility and Design Certification Boundaries*. Idaho Falls, ID. Prepared for Department of Energy. Accessed at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CB8QFjAA&url=https%3A%2F%2Finlportal.inl.gov%2Fportal%2Fserver.pt%2Fdocument%2F88341%2Fngnp_nuclear-industrial_facility_and_design_certification_boundaries_pdf&ei=ygvZU7j0EMrKigKDz4DQAg&usg=AFQjCNHUmxFA6XXW9Grv1P85Q2_6GtZUDw&sig2=rbvCFgQDEvNYBBqLrQ5lGA&bvm=bv.71778758,d.cGE&cad=rja

Idaho National Laboratory. (December, 2011). *NGNP 2011 Project Status and Path Forward.* Idaho Falls, ID. Prepared for Department of Energy. Accessed at https://inlportal.inl.gov/.../**ngnp**_project_2011

IAEA. (2012). *Status of Small and Medium Sized Reactor Designs.* International Atomic Energy Agency.

Johnson, M. R. (December, 2011). *SECY-11-0178 Insurance and Liability Regulatory Requirements for Small Modular Reactor Facilities*. Prepared for the NRC. Accessed at: http://pbadupws.nrc.gov/docs/ML1133/ML113340133.pdf

International Geothermal Association (IGA) (October, 2014). *Iceland - Direct Uses*. Accessed at: www.**geothermal**-energy.org/**direct_uses**/**iceland**.html

Kane, B. J. (December 10, 2010). *Nuclear Facility Land Designation (Work Order No. 27-LS0279)* Division of Legal and Research Services, Juneau, AK

Kinsey, J. Director Regulatory Affairs NGNP project. Interviewed on June 12, 2014 by Haley McIntyre

Kinsey, J. Director Regulatory Affairs NGNP project. Interviewed on June 30, 2014 by Haley McIntyre

Kiss, C. (2013). Update on Cogeneration in Europe. *COGEN Europe Annual Conference*, (p. 18). Hungary.

Liu, Z., & Fan, J. (2014). Technology readiness assessment of Small Modular Reactor (SMR). *Progress in Nuclear Energy*, 20-28.

Makhijani, A., & Boyd, M. (2010). *Small modular reactors: No solution for the Cost, Safety, and Waste Problems of Nuclear Power.* Washington, D.C.: Institute for Energy and Environmental Research and Physicians for Social Responsibility.

Mays, Gary. (July 8, 2014). *Licensing and Siting Challenges for Integrated Energy Systems*. Presentation for Integrated Nuclear-Renewable Energy Systems Foundational Workshop. Idaho National Laboratory

Mendivil, G. Commissioner's Office of the Alaska Department of Environmental Conservation. Correspondence Jun 24, 2014 with Haley McIntyre

Micklethwait, J. e*ditor*. (June 1, 2013). *Nuclear Power Fracked off: Thanks to cheap natural gas, America's nuclear renaissance is on hold*. The Economist. Accessed at: http://www.economist.com/news/united-states/21578690-thanks-cheap-natural-gas-americas-nuclear-renaissance-hold-fracked

Murkowski, L. (2013). *Energy 20/20: A vision for Americas Energy Future.* Washington, DC: US Congress.

Next Generation Nuclear Plant. (April 16, 2012). *Risk-Informed Performance-Based Licensing Approach*. Presentation of Idaho National Laboratory. Idaho Falls, ID.

Nuclear Energy Institute. (October, 2010). *Position Paper: NRC Annual Fee Assessment for Small Reactors*. NEI Small Modular Reactor Licensing Task Force. Accessed at: http://pbadupws.nrc.gov/docs/ML1103/ML110380260.pdf

Nuclear Energy Institute. (2014). *US Nuclear Power Plants*. Nuclear Statistics. Accessed at: http://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants

Nuclear Future. (2013). Reactors Installed on Floating Plant. *Journal of the Institution of Nucelar Engineers and the British Nuclear Energy Society, 9*(6), p. 17.

Nuclear Future. (2014). Construction of Argentina's CAREM underway. *Journal of the Institution of Nuclear Engineers and the British Nuclear Energy Society, 10*(2), 19.

Nuclear Future. (2014). Construction of Argentina's CAREM Underway. *Journal of the Institution of Nuclear Engineers and the British Nuclear Energy Society, 10*(2), 19.

Nuclear News. (May, 2013). New ESBWR RAIs issued; no review of 4S report. *Nuclear News, 56*(6), pp. 26-27.

Nuclear Regulatory Commission. (December, 2007). *NUREG-1860: Risk-Informed and Performance-Based Licensing Structure for Future Plant Licensing*. Office of Nuclear Regulatory Research. Rockville, Maryland. Accessed at: http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr1860/

Nuclear Regulatory Commission. (September 22, 2009). *Backgrounder on Nuclear Power Plant Licensing*. Rockville, Maryland. Accessed at: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/licensing-process-bg.html

Nuclear Regulatory Commission. (August, 2012). *Report to Congress: Advanced Reactor Licensing* Rockville, Maryland. Accessed at: http://www.nrc.gov/reading-rm/doc-collections/congress-docs/correspondence/2012/frelinghuysen-08-22-2012.pdf

Nuclear Regulatory Commission. (March, 2013). *Draft – Summary Feedback on Four Key Licensing Issues Next Generation Nuclear Plant Project 0748*. Office of New Reactors. Rockville, Maryland.

Nuclear Regulatory Commission. (April, 2013). *License Fees*. Rockville, Maryland. Accessed at: http://www.nrc.gov/reactors/operating/licensing/license-fees.html

Nuclear Regulatory Commission. (April 7, 2014). A*bout NRC History*. Rockville, Maryland. Accessed at http://www.nrc.gov/about-nrc/history.html

Nuclear Regulatory Commission. (July 10, 2014a). *Part 50 – Domestic Licensing of Production and Utilization Facilities*. Rockville, Maryland. Accessed at: http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/

Nuclear Regulatory Commission. (July 10, 2014b). *50.12 Specific Exemptions*. Rockville, Maryland. Accessed at http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-0012.html

Nuclear Regulatory Commission. (July 10, 2014c). *Appendix A to Part 50 – General Design Criteria for Nuclear Power Plants*. Rockville, Maryland. Accessed at: http://www.nrc.gov/reading-rm/doc-collections/cfr/part050/part050-appa.html

Power. (2010). Players in the Small Nuclear Game. *Power, 154*(11).

Rascoe, A. (February 9, 2012). *U.S. approves first new nuclear plant in a generation*. Reuters. Rockville, MD. Accessed at: http://www.reuters.com/article/2012/02/09/us-usa-nuclear-nrc-idUSTRE8182J720120209

Nuclear Future (2013). *Reactors installed on floating plant*. Nuclear Future, vol 17.

Reuters. (February 7, 2013). *Update 2 – Exelon cuts nuclear upgrade amid low gas prices*. Thomson Reuters U.S. Edition. Accessed at: http://www.reuters.com/article/2013/02/07/utilities-exelon-idUSL1N0B7CG320130207

Rettig, Molly. (January 23, 2011). *Why Nuclear Energy is on Hold for Alaska.* Fairbanks Newsminer. Accessed at: http://www.newsminer.com/news/local_news/why- nuclear-energy-is-on-hold-for-alaska/article_51958987-2a69-5528-aa4b-fd2755913460.html

Roege, Paul Col. U.S. Army Ret. Senior Program Manager at INL. Interviewed on June 18, 2014 by Haley McIntyre and Michael Kuca

Rosner, R., & Goldberg, S. (2011). *Small Modular Reactors - Key to Future Nuclear Power Generation in the U.S.* Chicago: Energy Policy Institute at Chicago.

Smith, M. (November 6, 2013). *The 'nuclear renaissance:' What went wrong?* CNN. Accessed at: http://www.cnn.com/2013/11/06/us/atomic-economics/

Solan, D., Black, G., Louis, M., Peterson, S., & Carter, L. (2010). *Economic and employment impacts of small modular nuclear reactors.* Idaho Falls, ID: Energy Policy Institute, Center for Advanced Energy Studies.

SOFAME Technologies. (2003). *Major Poultry Processor Generates Power, Hot Water and Steam from Cogen Installation*. Accessed at: http://www.sofame.com/uploads/editor/documents/Case%20studies%20energy%20efficiency%20reduce%20greenhouse%20emissions%20climate%20change.pdf

Sunshine Oilsands Ltd. (2014). *Oil Sands Technology*. Accessed at: www.sunshine**oilsands**.com

Thompson-Slater, N. (April 30, 2014). *U.S. response to the nuclear accident at Fukushima Daiichi.* U.S. Energy Information Administration. U.S. Department of Energy. Washington DC. Accessed at: http://www.eia.gov/forecasts/AEO/nuclear_fuk.cfm

Toshiba Corporation. (2009). Applicability of Small Fast Reactor 4S for Oil Sands Recovery. *Laser Therapy, 18*(4), 317.

U.S. Congress, Office of Technology Assessment. (1994). *Power Sources for Remote Arctic Applications.* Washington, DC.

Vujic, J., Bergmann, R., Skoda, R., & Miletic, M. (2012). Small modular reactors: Simpler, safer, cheaper? *Energy*, 288-295.

Welling, C. (2010). *Department of Energy Experience with Small Modular Reactors,* Office of Nuclear Energy, US Department of Energy. ACEP SMR Exploratory Workshop. Anchorage, Ak.

World Nuclear Organization. (July, 2014). *Nuclear Powered Ships*. London, United Kingdom. Accessed at: http://www.world-nuclear.org/info/non-power-nuclear-applications/transport/nuclear-powered-ships/

World Nuclear Organization. (November, 2014a). *Nuclear Power in Russia*. London, United Kingdom. Accessed at: http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Russia--Nuclear-Power/ .

World Nuclear Organization. (November, 2014b). *Nuclear Desalination*. London, United Kingdom. Accessed at: http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Industry/Nuclear-Desalination/

Zhang, J., Kapernick, R., McClure, P., & Trapp, T. (2013). Lead-bismuth eutectic technology for Hyperion reactor. *Journal of Nuclear Materials*, 644-649.